ABSTRACT

KOLLAR, CHRISTOPHER DAVID. Characterizing Mountain Biking Use and Biophysical Impacts through Technical Trail Features: A Case Study of A Montane and A Coastal Plain Site in The U.S.A. (Under the direction of Dr. Yu-Fai Leung.)

Mountain biking, a mechanized form of outdoor recreation, has presented challenges for multiple-use management due to resource degradation and liability. Challenges with the inclusion of mountain biking partly result from the lack of empirical research for specific mountain biking elements. A recent development within mountain biking is the presence and use of technical trail features (TTFs). TTFs have been defined as armored natural features or built structures on trails that enhance mountain biking riding experiences through physical and mental challenges. This study aims to address and assess biophysical impacts caused by mountain biking TTFs in two distinct terrain settings. A coastal plain mountain biking site in Clayton, North Carolina was compared with a montane in Whitefish, Montana. A problem (census based) assessment method incorporating a circular observation zone of impact was used to assess TTF characteristics, trail elements, safety and management items, and biophysical impacts. Characterization of TTF impacts using technical opportunity groups (i.e., ground, traverse, aerial) provided more significant differences in biophysical impacts among groups at the coastal plain mountain biking site. However, the montane site yielded a higher frequency of TTFs and higher levels of biophysical impact like trail incision and root exposure. A proximity analysis of impact zones indicated that a higher frequency of clustering occurred at the montane site and challenged the use of singular impact zones to assess biophysical impacts. In addition to the research implications, another contribution

from this study was an interactive, web-based visitor impact visualization tool that assists resource managers with monitoring and addressing mountain biking impacts. However, future integration of human dimension research with biophysical impact research is needed to provide objective information to resource managers who are facing the challenge of incorporating or continuing mountain biking opportunities.

Characterizing Mountain Biking Use and Biophysical Impacts through Technical Trail Features: A Case Study of A Montane and A Coastal Plain Site in The U.S.A.

by
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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Natural Resources

Raleigh, North Carolina

2011

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DEDICATION

This thesis is dedicated to my family back home in Strongsville, Ohio. Their love and support over the years has been invaluable. My family has been my support system for every challenge I face. Our struggles and joys have been shared together and as a family we have accomplished so much. Thank you Mom, Dad, April, David, and Jamie. I love you.

BIOGRAPHY

Christopher Kollar was born and raised in Strongsville, Ohio. In 2003 he came to North Carolina State University on an athletic scholarship for cross country and track and field. During that time he began his academic studies in biology, chemistry, and environmental sciences. After graduation from undergraduate study at North Carolina State University, he spent one year in graduate study and research within the Physiology Department. In 2009 he switched his graduate study from Physiology to Natural Resources. His interests include trail recreation, environmental impacts, and recreation experiences.

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank my committee of Dr. Yu-Fai Leung, Dr. Roger Moore and Dr. Gary Blank. Their seemingly endless guidance and efforts have made this thesis possible. Specifically, I would like to thank Yu-Fai for guiding me the past two years. Yu-Fai has provided me with so many opportunities like attending and presenting at conferences and contributing to projects involving the university, and local, state, and national parks. Besides contributing to my thesis, I would like to thank Roger and Gary for contributing to my education and personal development through classes, projects, and overall guidance. I would like to deeply thank Dr. Fikret Isik for helping me with the statistical analyses used in this study. Also, I would like to thank Dr. Dorothy Anderson and Dr. Karla Henderson for their help with shaping my thesis during the difficult, early stages.

This study was made possible by contributions from the Department of Parks, Recreation, and Tourism Management, the National Association of State Parks Directors, and Yosemite National Park. I would also like to thank the Montana Department of Natural Resources and Conservation for allowing me to use Spencer Mountain for this study. Specifically, I would like to thank Mike Collins of the Montana DRNC Northwest Land Office for his assistance. I would also like to thank my fellow graduate students and my brother Dave who assisted with data collection and provided guidance with my thesis and degree. Last but not least, I would like to express my gratitude to North Carolina State University, the College of Natural Resources, and all the faculty, staff, and students that have made my undergraduate and graduate education so special.

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CHAPTER 1: Introduction

Natural resource management has evolved over time with increasing special use or management interests, government policy, and the assistance of science-based information (Decker, Brown, & Knuth, 1996). Greater inclusion of recreation into multiple-use natural resource management requires the development of science-based study (Moore & Driver, 2005). Growing demand for recreation in the United States resulted in the creation of the Outdoor Recreation Resource Review Commission (ORRRC) in 1958. Since ORRRC, science-based recreation management has progressed from activity-based (ABM), to experienced-based (EBM), to benefits-based (BBM) (Moore & Driver, 2005).

One important advancement during this progression was the creation of the recreation opportunity spectrum (ROS), a conceptual framework for relating experiences to the settings in which they occur as a function of environmental, social and managerial factors (Manning, 1999). Similar management techniques to the ROS have been introduced for trail recreation as experience zones and preferred-use trails (Webber, 2007). As outdoor recreation focused natural resource management continues to develop, the idea of multiple use management begins to take on a whole new meaning. Multiple-use management policies, especially those wanting to incorporate extreme sports, are facing challenges from resource degradation, liability, and incongruity with specific land management agencies (Ewert, Attarian, Hollenhorst, Russell & Voight, 2006).

As a diverse and emerging outdoor recreation activity, mountain biking presents an excellent example of the growing challenges faced by natural resource researchers and managers. Since the early 1970's mountain biking has shown significant growth in participation and diversification into several rider styles (Webber, 2007; Ruff & Mellors, 1993). Technological advancements coupled with direct user involvement have transformed simple mountain biking into a myriad of recreation experiences. Mountain biking has presented a management paradox of providing appropriate mountain biking experiences while reducing biophysical impacts (e.g., erosion) that add to those experiences (Symmonds et al., 2000). A survey of 50 U.S. State Park Directors found that only 11% of states had a mountain biking management plan even though 66% reported that resource degradation from mountain biking was a problem (Schuett, 1997). The mountain biking management paradox is even more complex today as resource managers are faced with the challenge of incorporating an increasingly diverse, and expanding user group without knowing the different biophysical impacts attributed to distinct rider styles (Chavez, Winter, & Bass, 1993).

Since mountain biking is changing so rapidly, a new assessment methodology is needed to quantify on- and off-trail biophysical impacts caused by current forms of mountain biking use. Initial studies by Wilson & Seney (1994), Thurston & Reader (2001), and Chiu & Kriwoken (2003) used methods (i.e., experimental applications) that provided the groundwork for biophysical impact indicators for mountain biking as a whole. However, an advancement is research methodology is needed to parallel the development of mountain biking. One important development within mountain biking is the incorporation of technical features often referred to as technical trail features (TTFs). TTFs have become an integral part of mountain biking because they can increase trail challenge (Webber, 2007). It has been suggested that TTFs are intended to create challenging experiences at mountain biking sites where natural trail challenge is not provided by terrain (Kollar & Leung, 2010). As partnerships between mountain biking associations and natural resource managers continue to develop and mountain biking associations continue to create guidelines for TTFs as seen in Webber (2007), research is needed to better understand the characteristics of TTFs, the resulting biophysical impacts caused by the presence and use of TTFs, and how those impacts vary from site to site.

Exclusion of TTFs from previous mountain biking studies has resulted in a significant gap within visitor impact research. Only two peer-reviewed studies (Newsome & Davies, 2009; Pickering, Castley, Hill, & Newsome, 2010a) have addressed TTFs and their association with biophysical impacts, and neither was conducted in the United States. Further research is needed to develop a methodology that is applicable to different types of mountain biking sites and TTFs since mountain biking features and biophysical impacts are not confined to one site or one part of the world. Consequently, a TTF categorization system would be helpful for understanding and characterizing relationships to biophysical impacts. If established, this system would provide insight into how mountain bikers utilize and manipulate natural resources to attain desired recreational experiences. Improving assessments of developing mountain biking use will help alleviate mixed perceptions about mountain biking use and the resulting biophysical impacts. Mixed perceptions often result in inconsistent access and management that continues to frustrate recreationists and natural resource managers.

1.1 Research Goal and Objectives

The overall goal of this study was to enhance our current understanding of mountain biking by examining TTFs. There were two research objectives. First, this study built upon a previous methodology created in Pickering et al. (2010a) to develop an adaptive assessment methodology that would capture the biophysical impacts caused by mountain biking TTFs. In this study we analyze TTFs as a whole and as groups of TTFs to better understand their association with biophysical impacts. The study examined mountain biking biophysical impacts at two distinct physiographic regions (i.e., montane and coastal plain) to test the utility of a previously developed conceptual framework. Two physiographically distinct mountain biking sites were used to determine if biophysical impacts differ from site to site based on environmental characteristics. The second research objective was to analyze the spatial organization of TTFs for patterns in TTF arrangement and implications toward the assessment of biophysical impacts.

1.2 Study Significance

This study is important for several recreation resource research and management purposes. First and foremost is addressing the gap in knowledge about mountain biking use and related biophysical impacts by incorporating TTFs into an assessment methodology. The second purpose is continuing development of an adaptive assessment methodology capable of capturing the biophysical impacts associated with a variable recreation group (i.e., rider styles) and diverse settings (i.e., montane vs. coastal plain). Another potential contribution of this research is informing natural resource managers about decisions to plan and create more sustainable mountain biking sites that incorporate TTFs. Finally, discovering patterns relating to the spatial distribution of TTFs and resulting biophysical impacts could provide insight for designing sustainable mountain biking sites while preserving desired recreational opportunities.

CHAPTER 2: Literature Review

2.1 Mountain Biking

Mountain biking first emerged in Marin County, California during the 1970's by cyclists looking to explore unpaved surfaces (Hopkin & Moore, 1995; Ruff & Mellors, 1993). The capability of traveling at higher speeds and covering longer distances while riding on multiple surfaces allows for a substantial range of access. Consequently, mountain bikers can now access remote backcountry locations that had previously seen little recreational use and require little management attention (Chavez et al., 1993). In addition, mountain bikers have added to the already crowded multiple-use urban and urban-proximate trails shared by horseback riders and hikers. In the United States, attraction to this recently established recreation activity has led to an increase of mountain bikers from an estimated 25 million in 1995 (Hopkin & Moore, 1995) to 51 million in 2008 (Cordell, 2009).

The growing size of the mountain biking population and the biking industry created a need for organization. Like other established recreation groups, mountain bikers have united to form international (e.g., International Mountain Biking Association), national (e.g., National Off-Road Bicycling Association), regional (e.g., Southern Off-Road Bicycling Association), and local (e.g., Triangle Off-Road Cyclists) mountain biking associations. These organizations promote, organize, and fund mountain biking interests in their own communities and throughout the world. To meet the demand of their users, mountain biking associations have formed working relationships with resource managers to fund, design, and construct mountain biking trail systems. Although such partnerships can be productive, these services are provided with little guidance from empirical research.

As mountain biking expanded and organized, another development occurred within mountain biking with the emergence of multiple rider styles. In 2007 IMBA formally recognized six rider styles: all-mountain, cross-country, downhill, free ride, racing, and urban (Webber, 2007). Each rider type can be distinguished by its desired recreational experience whether it is related to surface type, topography or challenge (**Table 1**). Consequently, resource managers are not only faced with the challenge of incorporating a new, large, and expanding user group but they also must understand the different needs and environmental impacts attributed to distinct rider styles (Chavez, et al., 1993).

Table 1: Specific Rider Styles Found within Mountain Biking

Rider Type	Description
All-Mountain	Riders seeking a variety of trails, especially those providing technical challenge. This style focuses on climbing and descending on various terrain.
BMX or Dirt Jumpers	Riders looking for areas dedicated for jumping features. These riders often participate in other riding styles but focus on jumps.
Cross Country	Riders orientated towards longer distances (10-100 miles), multiple connecting loops and natural obstacles.
Downhill	Riders using specialized equipment on challenging, downward trails. This riding style is popular at ski resorts during the summer months.
Free Ride	Riders looking for technical challenge through features like rocks, bridges, jumps, logs, and drop-offs. Free riders can be found on all trails from cross country to dedicated experience zones.
Racing	A competition style of riding where riders race against each other and/or the clock. This style involves traveling over various terrain and features from a starting point to a finishing point.
Urban	A style of riding related to BMX but focusing on riding over challenging man-made features.

* Table adapted from Webber (2007), Newsome & Davies (2009), and IMBA (2009).

2.2 Mountain Biking Research

Compared to many other outdoor recreation activities mountain biking has received less research attention (Hopkin & Moore, 1995; Marion & Wimpey, 2007; Pickering et al., 2010a; Pickering, Hill, Newsome, & Leung, 2010). Most mountain biking specific research has focused on social concerns like multiple use conflicts, user preferences, and the effectiveness of management techniques. Little research has focused solely on the biophysical impacts of mountain biking use (Thurston & Reader, 2001; Marion & Wimpey, 2007). Those studies that have examined mountain biking impacts have done so in comparison to other recreation activities like hiking and horseback riding (Marion & Wimpey, 2007; Pickering et al., 2010b; Turton, 2005; Wilson & Seney, 1994). Much less is known about the biophysical impacts of mountain biking that are attributed to specific rider styles (Newsome & Davies, 2009; Pickering et al., 2010a).

Initial biophysical impact research regarding mountain biking focused on disturbances like soil compaction, erosion, trail widening, and vegetation trampling (Cessford, 1995; Wilson & Seney, 1994). Further studies explored the severity of those biophysical impacts by comparing different trail surfaces, rider behaviors, trail conditions, and trail positioning (i.e., slope and curvature). Results from these studies suggested that most biophysical impacts were related to inappropriate behaviors (e.g., skidding and braking), wet and muddy trail conditions, steep slopes, and curves (Goeft & Alder, 2001; Marion & Leung, 2001; White, Waskey, Brodehl, & Foti, 2006).

More recent biophysical impacts studies found wildlife disturbance (Davis, Leslie, Walter, & Graber, 2010; Taylor & Knight, 2003), human waste (Marion & Wimpey, 2007; Pickering et al., 2010b), and spore transmission (Pickering & Mount, 2010) were associated with mountain biking use. A further advancement in mountain biking research came from the assessment of cross-regional biophysical impacts from mountain biking by White et al. (2006). Specifically, this study compared the incision and width of mountain biking trails at five common ecological regions in the Southwest, United States. An important conclusion, one supported by previous mountain biking research, was the association of increasing slope with increasing trail incision and erosion. Although previous mountain biking research acknowledged the consequences of increasing slopes, no study has considered the ecological significance of mountain biking on the different slopes that characterize montane and coastal plain sites. The latest progression of biophysical impact research has involved the assessment of informal trails and TTFs (informal or formal) (Newsome & Davies, 2009; Pickering et al., 2010a).

2.3 Technical Trail Features

Speed and technically oriented outdoor recreation pursuits like mountain biking, skiing, water skiing, snowboarding, and skateboarding, often involve manipulation of the environment by recreationists to provide desired experiences. In the case of mountain biking, TTFs are a prime example of how natural environments can be modified to provide opportunities for desired recreational experiences. Where demand for mountain biking experiences are high and management is slow to respond, trails and TTFs are created informally (Newsome & Davies, 2009). Mountain biking TTFs, whether formally or informally created, are neither simple nor homogenous. At least 20 different types of TTFs have been identified along with associated construction and safety standards (Carter, 2004; DeBoer, 2003; Webber, 2007). Examples of individual TTF types (**Figure 1**) include ladder bridges, skinnies, jumps, drop offs, berms, mounds, and whoop-de-doos (**Appendix A)**. The overall composition of individual TTF types can range from natural materials (e.g., wood, rocks, soil, leaf litter) to non-natural materials (e.g., metal, plastic, cement, carpet). Due to the high variability in construction, composition, positioning, shape, and size of individual TTFs, the association of individual TTF types and specific environmental impacts is often difficult.

Figure 1: Pictures of Technical Trail Features
* TTF names clockwise from top left: ladder bridge, jump, berm, a-frame, skinny, log pile

Technical features are new to mountain biking but they are not new to outdoor recreation in general. Other outdoor recreation activities (e.g., inline skating, skateboarding, skiing, snowboarding, water skiing, and wake boarding) have incorporated technical features (e.g., jumps, ramps, moguls, and grind rails) into recreational settings from as early as the 1930's when Norwegian skiers introduced freestyle skiing (McMahon, 1997). The difference lies with the surface where the recreation activity is being performed. In comparison to other recreation activities, mountain biking TTFs occur directly on the earth's surface instead of an overlying surface (e.g., pavement, snow, water). Without an overlying or hardened surface to shield against mountain biking TTF use, a potential for biophysical impacts emerges. Therefore, the transfer of technical features from other recreation activities to mountain biking, warrants further research to understand the potential biophysical impacts and how to appropriately incorporate them.

TTF placement is critical for the overall sustainability of mountain biking areas and for enhancing rider experiences (DeBoer, 2003). TTFs can exist on designated trails or off trail in cleared areas or natural vegetation (Pickering et al., 2010a). Although resource managers are beginning to incorporate TTFs into their mountain biking sites, many TTFs are still created informally. Informal TTF locations rely heavily on providing opportunities for certain recreational experiences rather than potential for biophysical impacts. The "bandit" or informal nature of TTF creation also leads to placement in isolated areas or heavy vegetation where visibility and potential for management response are low. As a result, informal TTFs and corresponding informal trail networks often contribute to significant environmental depreciation through vegetation trampling, soil erosion, sedimentation, littering and the removal of natural resources to construct TTFs (Newsome & Davies, 2009; Pickering et al., 2010a; Turton, 2005). The spatial organization of TTFs can also affect the number and degree of resulting biophysical impacts. Science-based planning could curtail potential biophysical impacts by organizing TTFs into more sustainable networks. If sustainable networks are to occur we must first understand how TTFs are being utilized spatially and what biophysical impacts are associated with TTF use.

2.4 Research on Technical Trail Features

The creation of TTFs has only recently received attention from visitor impact research. Newsome & Davies (2009) conducted the first study to examine the presence of informal TTFs and their associated biophysical impacts. Since the acknowledgement of TTFs in recreational settings, it has become a challenge for researchers and mountain bikers to define them. IMBA has defined TTFs as obstacles on the trail requiring negotiation (2004) and natural obstacles that add challenge by impeding travel or features introduced to the trail to add technical challenge (2009). Newsome & Davies (2009) provided the first research definition for TTFs as "elements that enhance the character or difficulty of a trail". A more comprehensive description was provided by Kollar & Leung (2010) where TTFs were defined as "armored, natural features or built structures that enhance mountain biking riding experiences through physical and mental challenges". Definitions for TTFs continue to evolve with our understanding of these features and how they are used in recreational settings. A comprehensive understanding of TTFs and their relationship to mountain biking could remove a barrier between managers and riders.

Another reason mountain biking TTF research is important is that it provides a system for distinguishing biophysical impacts among rider styles, and other recreationists (Newsome & Davies, 2009; Pickering et al., 2010a). TTFs are becoming increasingly popular throughout mountain biking and at multiple-use recreation sites. Recent research has found frequencies of one TTF for every 140 meters of trail or 1:140 meters (Newsome & Davies, 2009), 1:135 meters (Pickering et al., 2010a) and 1:149 meters (Kollar & Leung, 2010). However, we must keep in mind that TTFs are not always built independently and are frequently developed into combinations or networks as reported in Pickering et al., (2010a). This presents another challenge to visitor impact researchers because the systematic point sampling methods employed previously in mountain biking impact studies might not be appropriate for study of TTFs. An examination of alternative trail assessment techniques by Marion and Leung (2001) found that systematic point sampling methods missed occurrences of uncommon trail problems, like TTFs, and were inefficient for documenting infrequent trail characteristics. In such cases, Marion and Leung (2001) recommended the use of census-based problem assessment methods where infrequent trail problems can be assessed on an event by event basis and trail characteristics can be predefined (**Table 2**). Consequently, Pickering et al. (2010a) and Kollar & Leung (2010) elected to use problem assessment sampling methods where each TTF was treated and assessed as an individual disturbance event. Further application of this adaptive assessment method is needed to strengthen the assessment of biophysical impacts caused by TTFs and to examine significant spatial relationships as well.

Table 2: Advantages and Disadvantages of Trail Assessment Approaches

Survey Type	**Advantages**	**Disadvantages**
Problem-based	-Permits rapid assessments focused on trail problems of greatest management concern. -Characterizes the condition of the entire trail.	-Focuses on trail problems. -Not able to characterize average conditions for indicators such as trail width or muddiness. -Not sensitive to small changes.
Sampling-based	-Permits rapid assessments of general trail conditions.	-Might not accurately characterize trail problems unless a large number of sample points are used. -Not sensitive to small changes.

*Adapted from Monz, (2010)

Pickering et al. (2010a) advanced TTF research by creating a specific protocol for assessing biophysical impacts of TTFs found at the Blackbutt Forest in southeastern

Queensland, Australia. TTFs were assessed individually or in combination for social, environmental, and management variables. Descriptive results from the study found a total of 116 TTFs, representing eight individual TTF types, with jumps being the most common TTF type. The safety assessment showed only five TTFs receiving high safety ratings, most likely resulting from the absence of precautionary methods such as signage, optional lines, and filter points. Optional lines and filter points are used to direct riders towards or away from TTFs (**Appendix A**). Meanwhile, almost all features received good or moderate condition scores, especially the jump features. The biophysical assessment found a direct association of TTFs with removal of vegetation, soil, and rocks to construct TTFs, exposure to bare ground, and the introduction of littering and foreign materials. A one-way ANOVA for continuous assessment variables found significant differences between the 8 individual TTF types for TTF length, maximum height, maximum width and for width of bare ground, width to understory, width to shrub layer and width to trunks. Pickering et al. (2010a) concluded that the TTFs degraded the environmental value of the forest in terms of soil and vegetation and that the area and type of impacts varied among the TTFs. However, there might not be a need to distinguish between each individual TTF for biophysical impact assessment and resource management.

2.5 TTF Conceptual Frameworks

One way to better understand TTFs and their associated biophysical impacts is to develop conceptual frameworks where TTFs are placed into distinct descriptive categories based on similar functions or characteristics. If TTF conceptual frameworks can be established then we would be able to identify and study relationships of biophysical impacts for TTFs as a whole instead of highly variable individual features. Key TTF elements can be derived from existing TTF definitions and used to create distinct descriptive categories. Three conceptual frameworks that have evolved from those definitions include: overall composition (e.g., rocks, wood, soil), challenge opportunity, and technical opportunity.

Initial research efforts to categorize TTFs focused on resource manipulation and feature composition. In their mountain biking publications, IMBA has identified three TTF categories: existing natural features, enhanced natural features, and engineered (man-made) structures (Webber, 2007; IMBA, 2009). Each TTF was categorized by IMBA according to the manipulation of resources and the overall composition of each TTF. Natural resources found onsite that were not moved would be placed in the existing natural trail feature category. Natural resources that were relocated onsite or brought to the site would fall in the enhanced natural trail features category. Finally, foreign, artificial materials brought onsite would be part of the built trail feature category. This is a simple and logical method for categorizing TTFs and fits well with the ROS experience opportunity settings (e.g., rustic, developed). This particular method of categorization tells us how TTFs were constructed but it does not necessarily tell us how they are used by mountain bikers. Also, the biophysical impacts caused by TTFs are not limited to the features themselves. Consideration should be given to how mountain bikers enter, exit, or avoid the TTF as well.

A second method for categorizing TTFs is through the opportunity for challenge. The term "technical trail feature" itself suggests some kind of challenge. Several issues arise when trying to determine challenge levels of TTFs. First of all, each individual TTF type (e.g., jump) can be modified to increase or decrease challenge. This can be done by simply adjusting the height or length of the feature. Secondly, challenge is highly dependent on the individual. Two mountain bikers can travel over the same TTF with one thinking it was very challenging and the other finding no challenge at all. The level of challenge can be situational as well. A certain TTF might have a high challenge rating when it is windy or wet but is not as challenging when conditions are fair. To account for the variability in challenge, researchers have experimented with indices like experience-use history (EUH) that incorporate variables such as frequency of participation, years of experience, and skill level to determine levels of challenge (Ewert & Hollenhorst, 2004). For the purpose and scope of this study, challenge is too variable and not an appropriate method for categorizing TTFs.

The last method for categorizing TTFs focuses on technical opportunities. One commonality between all TTFs is that they were built for a specific purpose or function. Each TTF provides the mountain biker with a particular technical opportunity where the mountain biker must enter the feature at "point A" and exit the feature at "point B". While the mountain biker proceeds from "point A" to "point B" he or she is provided one of the following technical opportunities: 1) natural surface; 2) elevated artificial or enhanced surface; 3) above surface or aerial. This categorization was tested in a pilot study at Legend Park in Clayton, NC (Kollar & Leung, 2010). What resulted was an exhaustive categorization and description of TTFs based on the three derived technical opportunity groups: ground, traverse, and aerial (**Table 3).** Each individual TTF type fell into one of these three technical opportunity groups. This particular categorization of TTFs resulted in several significant differences between the three groups for TTF characteristics, biophysical impact, and trail characteristics. In addition significant differences resulted within the technical-based categories themselves for TTF and trail characteristics and biophysical impacts. The technical-based categorization developed in the Legend Park pilot study (Kollar & Leung, 2010) was considered to be more effective than the composition-based categorization for determining biophysical impact levels but needs the support of further research with the inclusion of more individual TTF types.

Table 3: Characteristics and Examples of Technical Opportunity Framework

Technical Opportunity Groups	Characteristics	TTF Examples
Ground TTFs	Offers a technical opportunity while riders are on the natural surface.	Berm, ditch, rock garden, whoop-de-doo
Traverse TTFs	Offers a technical opportunity while riders traverse from point "a" to point "b" on an elevated surface.	Bridge, boardwalk, ladder bridge, log cross, log jam, log pile, skinny, teetor-totter
Aerial TTFs	Offers a technical opportunity as riders move from natural and elevated surfaces into the air.	Drop-off, drop-in, jump, mound, tabletop

Research on mountain biking impacts has developed over time, from simply riding a bicycle off road to specific mountain biking elements. Initial research efforts indicated that mountain biking contributed to soil erosion, compaction, trail widening, and vegetation trampling. Further study determined that the biophysical impacts of mountain biking were significantly less than horseback riding but not significantly different than hiking. However, over time, mountain biking has evolved into multiple riding styles, which has changed our understanding of mountain biking impacts. The emergence of multiple riding styles and mountain biking elements (i.e., technical trail features) needs to be addressed (Newsome & Davies, 2009). However, incorporation of these poorly understood mountain biking elements poses a significant challenge to accurately assess and quantify the biophysical impacts.

CHAPTER 3: Methods

This chapter begins by stating the research questions of the study. The subsequent sections describe the study sites, assessment methodology, and analyses employed.

3.1 Research Questions

1. How do the type, quantity and frequency of TTFs at a montane mountain biking site compare to those at coastal plain site?
2. How do the biophysical impacts of TTFs found at a montane mountain biking site compare to those found at coastal plain site?
3. What is the most effective way to characterize TTFs (individual, composition, or technical opportunity) for representing their associated biophysical impacts? Does the effectiveness of TTF characterization change from the montane mountain biking site to coastal plain site?
4. How does the spatial organization of TTFs at a montane mountain biking site compare to those at a coastal plain site and how that affects the resulting biophysical impacts?

3.2 Study Sites

The primary study site was Spencer Mountain, a 2,700 acre urban-proximate recreational site located four miles west of the Town of Whitefish in Montana (**Figure 2**). Urban-proximate refers to wilderness or natural areas found near large urban populations (Ewert, 1998). Several mountain biking sites in the Northern Rocky Mountains of the United States were considered for the montane site using information from popular mountain biking sites (e.g., www.dirtworld.com). Montane refers to alpine areas having steep slopes and thin soils that are vulnerable to human and natural disturbances (Gordon, Dvorak, Jonasson, Josefsson, Kocianova, & Thompson, 2002). Spencer Mountain was chosen as the montane site for its steep terrain, length of trail, and number and variety of TTFs. In 2010, according to an environmental assessment by the Montana Department of Natural Resources and Conservation (DNRC), the site was heavily timbered with many areas having slopes exceeding 25% (Lorch, 2010). The length of trail (10 miles), number (approximately one hundred) and variety (several) of TTFs at Spencer Mountain were comparable to the pilot study site, Legend Park, in Clayton, North Carolina.

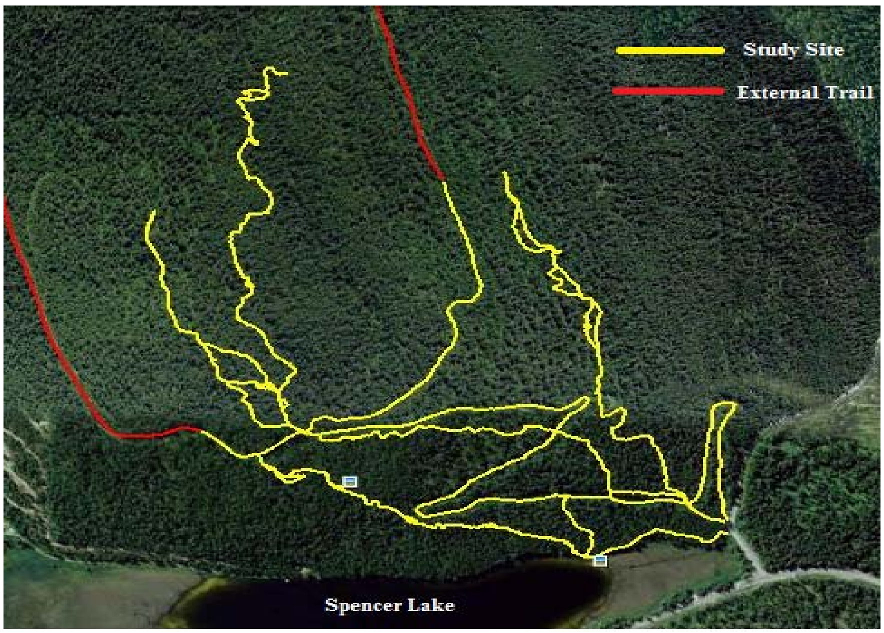

Figure 2: Montane Study Area

Spencer Mountain is managed as a State Land Trust site under the authority of Montana's DNRC. An annual state land trust recreation license must be purchased to recreate at the Spencer Mountain site. This study was permitted by Montana's Northwest Land Office, State Land Trust project manager (Michael Collins) who approved the study design and granted access to the site. Geospatial Information System (GIS) maps of the site were provided by the Montana Department of Natural Resources and Conservation. The local mountain biking association, Flathead Fat Tires, works with the Montana DNRC to manage trails, TTFs, and rider behavior. Most TTFs at Spencer Mountain exist formally however there has been documentation of informal trail creation and it is likely that some TTFs were created informally (Kallandar, 2010).

The coastal plain study site was Legend Park, a 100 acre, heavily forested urban-proximate mountain biking site located two miles from the Town of Clayton, North Carolina (Miller, 2006). Coastal plain refers to flat or gently sloping terrain, soil parent materials of sand and clay and pine savannas with mixed hardwood forests (Goebel, Palik, Kirkman, Drew, West, & Penderson (2001). Legend Park, part of a network of mountain biking sites in the Raleigh-Durham-Chapel Hill area of North Carolina, was found through a popular, local mountain biking website (www.triangle.mtb.com). Several mountain biking sites in the area were visited in the site selection process. Legend Park was chosen as the coastal plain study site for its length of trail (8 miles), and the number (approximately 100) and variety (several) of TTFs (**Figure 3**).

Groundbreaking of the trail system was led by mountain biking enthusiast Allen Tutt in 2002 (Miller, 2006). Initially a local mountain biking association N.C. FATS (which stands for fat tires associated with mountain biking) assisted the Town of Clayton with managing and maintaining the Legend Park site. In 2005, the N.C. FATS mountain biking club merged into a larger association called Triangle Off-Road Cyclists (TORC) which has decided to discontinue management of this particular site. Only a quarter of the land comprising Legend Park is owned by the Town of Clayton. The other 75% of the trail system extrudes into private land that permits recreational use under the management of the Town of Clayton. The mountain biking area is one segment of a larger public park managed by the Town of Clayton's Park and Recreation Department. Overall, the mountain biking site contains over eight miles of trail, 75 technical trail features, and a TTF frequency of one for every 129 meters of trail (1:129m) (Kollar & Leung, 2010).

Figure 3: Coastal Plain Study Area

3.3 Sampling & Field Procedures

All TTFs were assessed using the track problem assessment method (Marion & Leung, 2001). The total number of TTFs (both sites) examined in this study was 278. Before any field work occurred, a comprehensive identification guide was created with pictures and technical terms for all known mountain biking technical trail features that could be encountered (**Appendix A**). The assessment methodology used in this study was adapted from previous Australian studies by Pickering et al. (2010a) and Newsome & Davies (2009). Before the assessment period, a draft assessment protocol was created using assessment items from Pickering et al. (2010a), Newsome & Davies (2009), and several new items. Assessment items focused on biophysical impacts, trail characteristics, and TTF characteristics. After several field tests at Legend Park and revisions, the final instrument (assessment protocol and visitor impact monitoring survey) (**Table 4**) was finalized and printed.

The instrument was pilot tested in a study by Kollar & Leung (2010), and has been modified to enhance certain assessment variables or incorporate new variables. Newly incorporated assessment variables were TTF group, TTF naturalness, and ground cover. TTF group and naturalness were added for classification and assessment purposes. A ground cover assessment item was added to examine the vegetation type for indication of trampling. Modified assessment variables were TTF safety and canopy cover. The assessment of TTF safety was adjusted from a simple judgment to a calculation based on TTF condition and the presence of precautionary elements like optional lines and signage. Canopy cover assessments were also adjusted from simple judgments to a calculation using a spherical densitometer (Cook, Stutzman, Bowers, Brenner, & Irwin, 1995). Modification of the instrument was needed to increase the extent and accuracy of the assessment and reproducibility of the methods.

Another modification from the previous assessment method (Pickering et al., 2010) was the use of a circular observation zone (COZ) to increase measurement accuracy and consistency (**Figure 4)**. Specifically, if a mountain biker uses a TTF then biophysical

Table 4: A List of Field Assessment Items and Procedures

Assessment Item	Description
TTF Characteristics	
GPS Waypoint	Indicate yes or no
Name	Record name given for GPS waypoint
Group Type	Indicate ground, traverse or aerial
Feature Type	Provide name of Individual TTF (berm, jump, mound, etc.)
Construction Material	List all materials found in TTF (wood, nails, rocks, etc.)
Naturalness	Indicate natural, enhanced or built based on materials
Height	Record maximum and minimum using measuring tape (cm)
Width	Record maximum and minimum using measuring tape (cm)
Length	Record maximum using measuring tape (m)
Safety & Management Concerns	
TTF Condition	Rate based on age and appearance (poor, good, or like new)
TTF Safety	Use criteria to evaluate. Rate low, moderate, high or very high.
Signage	Indicate Present or Not Present
Filters or Choke Points	Indicate Present or Not Present
Optional Lines*	Indicate Present or Not Present
Fall Zones*	Indicate Present or Not Present
Biophysical Impact Indicators	
Trail Incision	Record maximum incision depth using ruler (cm)
Area of Disturbance	Record width and length using measuring tape of barren area (m^2)
Removal of Vegetation	Indicate Present or Not Present
Root Exposure	Indicate Present or Not Present
TTF Location to Trail	Record location of TTF (on trail, cleared area, vegetation)
Trail Characteristics	
Trail Type	Rate based on trail width (narrow: <60cm, one person: 60-140cm, two person: 140-200cm, 4 wheel drive: >200cm)
Trail Width	Take two measurements using measuring tape and record average (cm)
Trail Slope	Record using clinometer facing upslope (degrees)
Landscape Slope	Record using clinometer facing upslope (degrees)
Trail Aspect	Record using compass facing downslope (azimuth degrees)
Landscape Aspect	Record using compass facing downslope (azimuth degrees)
Recreation Users	Record type and amount of users contacted (hikers, bikers, etc.)
Canopy Cover*	Record using spherical densiometer (%)
Canopy Openness	Indicate based on canopy cover calculation (open: 0-25%, moderate: 26-74%, closed: 75-100%)
Understory Condition	Indicate understory coverage (poor, light, or thick vegetation)
Ground Cover*	Indicate vegetation type (grass, saplings, adult trees, shrubs)

* Items assessed only at Spencer Mountain.

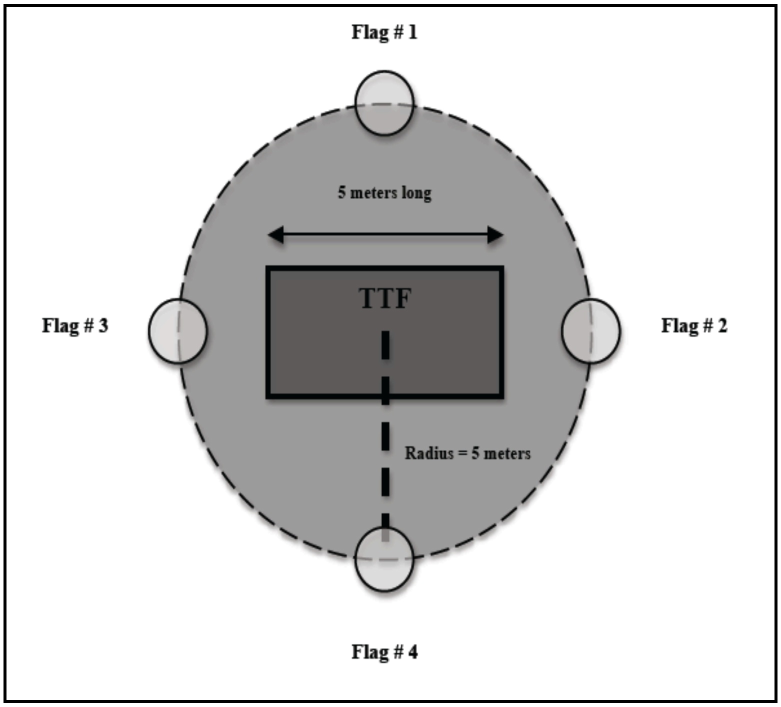

Figure 4: Circular Observation Zone of Biophysical Impact

impacts occur at the entrance of the feature and where the rider exits the feature. As prescribed by IMBA, TTFs should have fall zones where mountain bikers can safely exit the feature if they can no longer continue. Also designated by IMBA, TTFs should have optional lines for mountain bikers who do not wish to participate. The combined biophysical impact of mountain bikers entering, exiting, and riding around TTFs creates a broader zone of impact, the size of which varies with the size of TTF feature itself. To accurately and consistently assess the total biophysical impact resulting from TTF use, a circular observation zone was created using the TTF length as the radius. At the beginning of each assessment, the TTF length was recorded and four flags were placed to indicate the outer edge of the observation zone. All subsequent trail, TTF, and biophysical assessments were performed within those COZs.

3.4 Data Collection

Assessment periods at each site lasted ten to fifteen days with individual TTF assessments lasting five to ten minutes depending on the size of the feature. The study period consisted of daylight hours and optimal weather conditions from November 3rd to November 19th, 2009 at Legend Park and May 14th to May 28th, 2010 at Spencer Mountain. Optimal weather conditions for trail assessment are dry periods with no organic debris or snow covering the trail surface. The two researchers walked each mountain biking site in its entirety and assessed each technical trail feature encountered. The research team consisted of the principal investigator who took the measurements and a previously trained research assistant who recorded data onto the visitor impact monitoring survey (**Appendix C**). A COZ was established around each TTF and then the survey instrument was applied. Standard trail measurement tools were used for the assessment procedure including a metric wheel, metric rulers, a SUUNTO® Tandem clinometer/compass combo, and a Garmin® geospatial positioning system (GPS) Unit (Oregon 550t with digital camera).

During both data collection periods the research assistant performed several assessments without aid from the principal investigator to allow for the assessment of an inter-observer reliability for the assessment methodology. All data were recorded on the pre-developed visitor impact monitoring surveys at the time of assessment. At Legend Park six visitor impact monitoring surveys were completed. During the Spencer Mountain assessment ten surveys were completed.

3.5 Data Analysis

After each assessment period, visitor impact monitoring survey entries were transferred to a Microsoft Excel® spreadsheet with the corresponding assessment codes. The final Excel® database was transferred to SPSS 18® for statistical analyses. The type of statistical analysis performed depended on the assessment method (i.e. categorical or continuous) of each item. A probability of 0.05 was used as the cut off point for significance in all statistical tests. Descriptive statistics were used for identifying general site characteristics like individual TTF frequencies and overall biophysical impact means. A non-parametric statistic, Pearson Chi-Square analysis (**Equation 1**), was used for nominal, ordinal, and interval assessment data (Pallant, 2007). In conjunction with the chi-square test, a Cramer's V statistic was calculated to determine the effect size of the independent variable on the categorical assessment items. Effect sizes were rated low, medium, or large based on the Cramer's V statistic and the number of categories within each assessment item (Pallant, 2007).

Equation 1: Chi-Square Analysis for Categorical Assessment Items

$$X^2 = \Sigma_{(n-1)} [(O_i - E_i)^2 / E_i]$$

where: X^2 equals Pearson's cumulative statistics
O_i equals the observed frequency
E_i equals the expected frequency
n equals the number of samples.

A one-way ANOVA (**Equation 2**) was used for analyzing variance of interval assessment data among the three technical opportunity groups developed in a previous study by Kollar & Leung (2010) (Pallant, 2007). Baseline data from the pilot study at Legend Park in North Carolina was used in conjunction with the data gathered from Spencer Mountain in Montana. Tukey's Honestly Significant Difference (HSD) post hoc test was employed to determine where the variance occurred within the one-way ANOVA (**Equation 3**) (Pallant, 2007). Superscript, lower case alphabetic symbols (e.g., [a,b,c]) were used to denote significant differences between the calculated means. Thus, mean values containing the same lower case alphabetic symbols were not significantly different.

Equation 2: One-way ANOVA for Continuous Assessment Items

$Y_{ij} = \mu + U_i + W_{ij}$

where: Y_{ij} is the j_{th} observation of the i_{th} technical opportunity group

Equation 3: Tukey's Post Hoc Test

$M_1 - M_2 / \sqrt{MS_w (1/n)}$

where: M = treatment/group mean
n = number per treatment/group

Comparing biophysical impact levels between the two study sites and the technical opportunity groups required a nested two-way between groups ANOVA (**Equation 4**). A two-way ANOVA tests the effect of two independent variables simultaneously on the dependent assessment items (Raudenbush and Bryk, 2002). The two independent variables used in this study were technical opportunity groups and mountain biking site location. In order to make direct comparisons, the technical opportunity groups were nested within the mountain biking site variable. A nested two-way ANOVA was chosen over a factorial two-way ANOVA because it allows direct comparisons of specific technical opportunity groups across sites. For example, it was more meaningful to compare aerial groups at Legend Park with aerial groups at Spencer Mountain than to compare each group at each site. The limitation of a nested-two ANOVA is that no interaction effect can be measured between the two independent variables (Raudenbush and Bryk, 2002).

Equation 4: Nested two-way ANOVA for Continuous Assessment Items

$y_{ijk} = \propto + S_i + X_j + e_{ijk}$

where: y_{ijk} is the k_{th} observation of the j_{th} technical opportunity group in the i_{th} site

Finally, data collected for several TTFs at each site solely by the trained research assistant was used to calculate an inter-observer reliability ratio. An inter-observer reliability ratio was used to calculate the degree of agreement among the raters in this study. This ratio provides one way to analyze the strength and reproducibility of the applied instrument for future research efforts.

3.6 Spatial Analysis

While performing the assessments all trails and TTFs were recorded into the Garmin Oregon GPS unit. A picture was taken at each TTF and georeferenced to the coordinates at the corresponding TTF location. Each TTF was waypoint averaged twice to increase the accuracy of the spatial recording. Waypoint averaging took place during the initial site visit and the official TTF assessment for a period of one minute. The Garmin® Oregon GPS unit features a wide area augmented system (WAAS) that uses satellites and ground stations to automatically correct the GPS signal. The accuracy of WAAS is reported as within three meters about 95% of the time (www.garmin.com). All trail, TTF, and picture recordings were transformed from the GPS unit to a computer using the Garmin® BaseCamp™ software. All data and pictures were then transferred from BaseCamp™ to the freeware Google® Earth. Once the GPS recordings were in Google Earth they were displayed using a Google Earth web plug-in and transferred to ESRI ArcGIS 9.3. A free toolbox can be downloaded from ESRI scripts to convert the Google® Earth data (.kml files) to ArcGIS® format (.shp files).

Once all trails and TTFs were transferred into ArcGIS® a simple table join was used to add the assessment data to each TTF. Supplementary raster (e.g., orthophotos) and vector (e.g., contours, hydrology, land use, streets) files for each site were downloaded from North Carolina's Johnston County GIS and Montana Natural Resource Information System (NRIS) GIS websites. All geospatial data for the Legend Park study site and Spencer Mountain site are projected in Lambert Conformal Conic projection system. Montana data were specifically projected in universal transverse mercator (UTM) coordinate system while North Carolina data were projected in North Carolina State Plane meters coordinate system.

Analysis of the spatial arrangement of TTFs at Legend Park and Spencer Mountain was performed using ESRI ArcGIS® software. Once all TTFs were transferred to ArcMap a proximity analysis was executed. Since the radius of the central observation zone was determined based on the TTF length, the average TTF length was used as the buffer size of the proximity analysis. At Legend Park the buffer size employed was 10.3 meters while at Spencer Mountain a 6.1 meter buffer was used. During the proximity analysis all buffer zones were dissolved so that TTFs arranged together would become a single cluster. Using the spatial analyst tool the buffer zones were exploded to multipart features so that TTFs would be represented as either individual TTFs or individual clusters. For this study, a cluster of TTFs was defined as three or more TTFs that were connected via their central observation zones.

CHAPTER 4: Results

Assessments at Legend park (coastal plain site) and Spencer Mountain (montane site) were taken in early fall of 2009 and summer 2010, respectively. The study periods were chosen because that is typically when soils are dry and not covered with leaf litter or snow. However, the months of May to August are typically the peak season for mountain biking activity (Symmonds et al., 2000). During the assessment of the coastal plain site two dog walkers, one trail runner and several mountain bikers were encountered. At the montane site hikers and dog walkers were commonly seen on the multiple use trail that led to the mountain biking trails but none on the actual mountain biking trails. Mountain bikers were seen on both the multiple use and mountain bike trails every day of the assessment period. On several occasions, the research team stopped assessments and yielded to oncoming mountain bikers as to not interfere with their experience and for safety reasons.

Initial assessments at both coastal plain and montane sites were lengthy as the research team adjusted to the procedure for completing thirty assessment tasks per TTF. As research period progressed, the time needed to assess each TTF went from an average of 30 minutes to around 10 minutes. The assessment items that took the longest field time to complete were canopy cover, vegetation cover, and safety ratings. Also, the assessments at the montane site took longer because more than twice as many TTFs were assessed and measurements were taken with tools and instruments while balancing on steep slopes.

The results section is organized based on the four research questions of this study. The main sections are divided by the nature of the assessment data, starting with descriptive analyses then moving to nonparametric, parametric and finally to spatial analyses.

4.1 Descriptive Analyses

4.1.1 Technical Trail Feature Characteristics

A total of 287 TTFs were assessed and analyzed in this study. The coastal plain site had a total of 86 TTFs while the montane site had a total of 201 TTFs. Despite the difference in total number of TTFs, both the montane and coastal plain sites each contained 14 different types of TTFs. However, the individual TTF types were not identical. The montane site did not have the rock gardens or tabletops found at the coastal plain site but it did introduce ditches and drop-ins to the assessment. The most common TTF types at the coastal plain site were the bridge and drop-off features, with 17 occurrences each (**Figure 5**), while jump features were the most common at the montane site with 50 occurrences (**Figure 6)**. The Montane site contained ten miles of trail and had a higher TTF frequency -- an average of one TTF per 70m of trail length (1:70m). The coastal plain site had a much lower TTF frequency of 1:150m with eight miles of trail.

Materials used to construct features were diverse and included bricks, concrete, grip tape, metal, nails, screws, plastic, rocks, wood, soil, carpet, and glue. These materials were condensed into the following four predominant categories; wood, metal, soil, and rocks (**Figure 7**). Wood (native and non-native) was the most dominant material used for constructing TTFs on both study sites. Native wood was used more frequently (71%) than foreign or pretreated wood in the construction of TTFs at the montane site (**Figure 8**). TTFs at the coastal plain site were more frequently (47%) built with foreign or pretreated wood. Compared to the coastal plain site, the montane site had higher percentages of natural materials such as soil, wood, and rocks. Each TTF was placed into a composition category

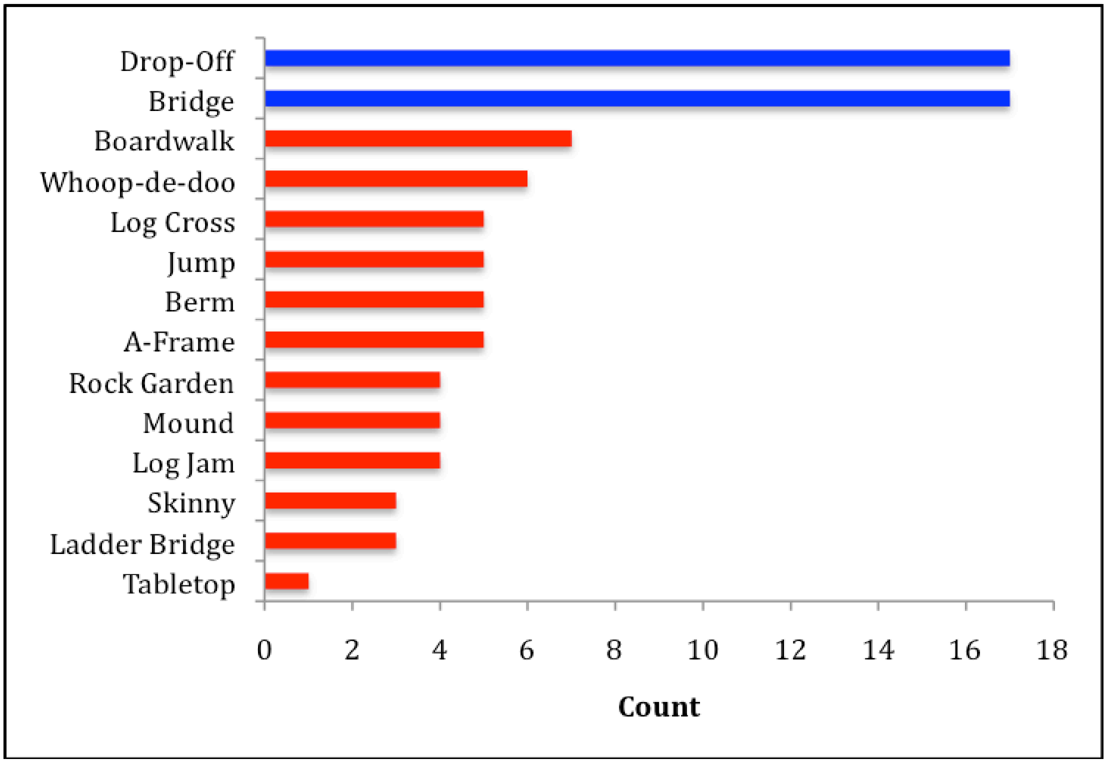

Figure 5: Coastal Plain Site Individual TTF Frequency

* Blue signifies most frequent TTF Type. Both Drop-Off and Bridge TTFs had a count of 17.

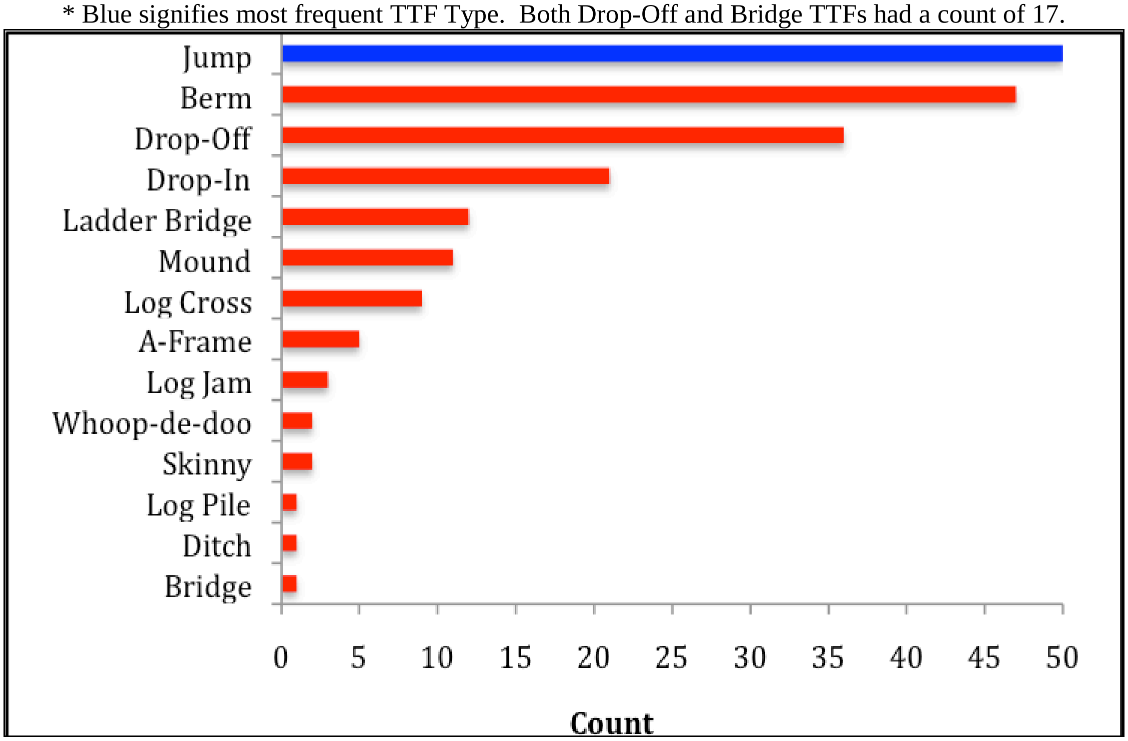

Figure 6: Montane site Individual TTF Frequency

* Blue signifies most frequent TTF Type

(i.e., natural, enhanced, or built) based on the materials used to construct them. The majority of TTFs at the coastal plain site (48%) were built using foreign materials while the majority of TTFs at Spencer Lake (46%) were enhanced using native materials. Overall, natural trail features were the least common comprising only 24% of all TTFs.

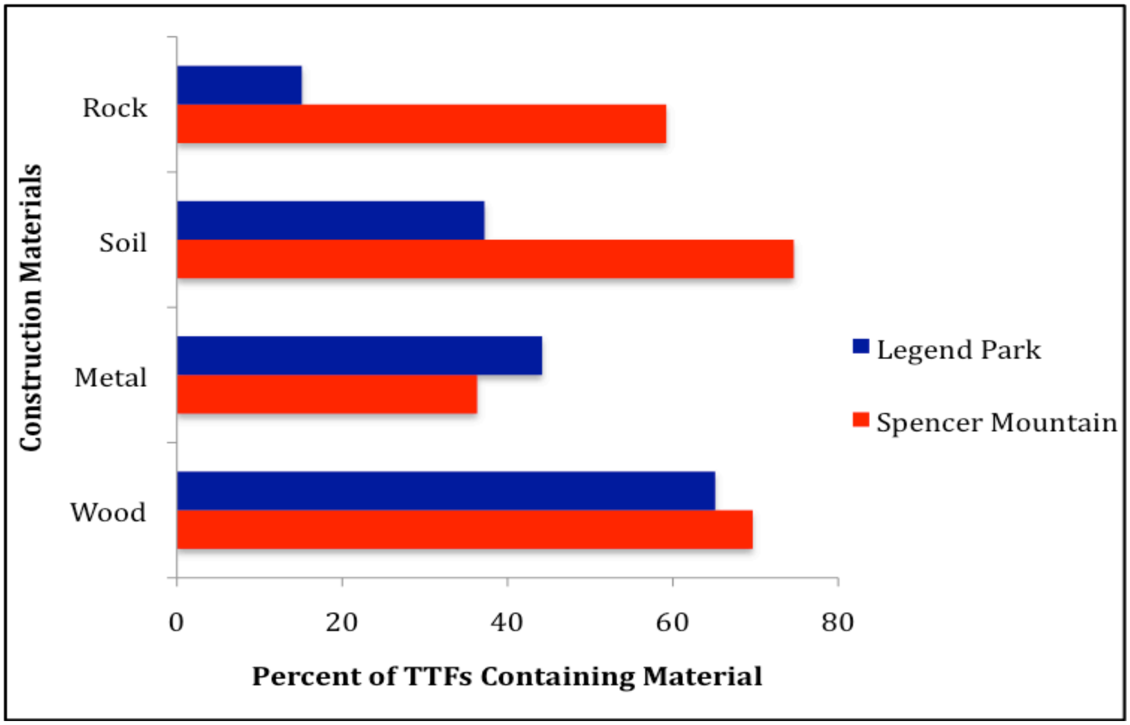

Figure 7: Predominant Materials Used to Construct TTFs
* Because many TTFs are made from multiple materials, the cumulative percentage exceeds 100%.

Mean TTF length, maximum height, and maximum width at the montane site were 10.3 m, 2.0 m, and 1.6 m respectively. Corresponding TTF dimensions at the coastal plain site were 6.0 m, 9.1m, and 1.7 m. The overall condition of TTFs was assessed at each site based on guidelines provided by IMBA (**Table 5**). Approximately two thirds of the TTFs at both sites were in good or new condition. Safety ratings, which incorporate TTF condition and the presence of optional lines, filter/choke points, fall zones and signage, were also calculated for all individual TTFs at each site. Nearly a quarter of the TTFs at the coastal plain site were rated low for safety and signs were only present for 4 TTFs. In contrast, the montane site had only 12% of TTFs with low safety ratings despite the absence of signage.

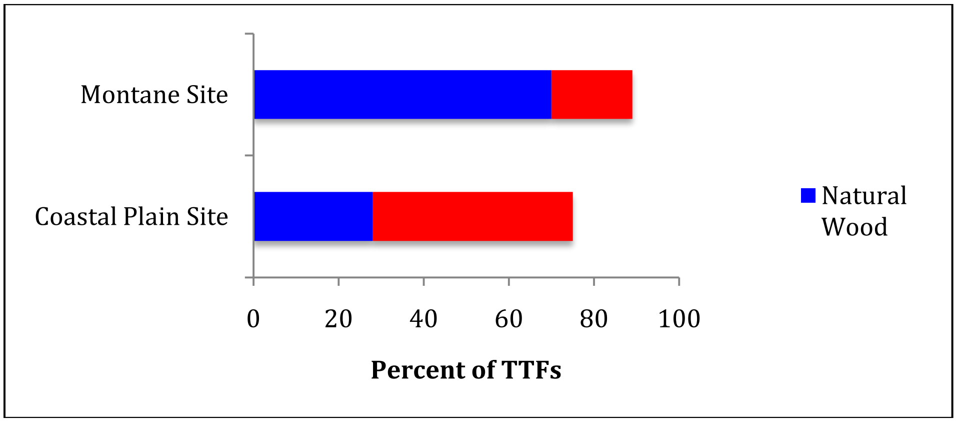

Figure 8: Percentage of TTFs Built with Natural or Foreign Wood
*** Some TTFs are built with both natural and foreign wood.**

Table 5: Safety Ratings and Condition Scores for TTFs

	Coastal Plain Site		**Montane Site**	
Assessment Variables	Count	%	Count	%
Condition Score				
Like New	7	55	72	28
Good	47	8	57	36
Poor	32	37	72	36
Safety Rating				
Very High	2	2	43	21
High	33	38	84	42
Moderate	29	34	50	25
Low	22	26	24	12
Optional Line Present*	-	-	104	52
Filter / Choke Point Present	12	14	28	14
Fall Zone Present*	-	-	146	73
Signage Present	4	5	0	0

* Assessment variable was applied only at Spencer Mountain

4.1.2 Overall Biophysical Impacts

Descriptive analyses were performed to examine the overall biophysical impact variables at the coastal plain and montane sites. All TTF assessment variables, discrete or continuous, indicated some level of biophysical impact. Summary statistics from the continuous and categorical biophysical impact variables are presented in **Tables 6 & 7,** respectively. Summary statistics from the continuous biophysical impact variables showed that mean trail slope at the montane site was 10.5 degrees than at the coastal plain site. TTFs at the coastal plain site had a mean area of disturbance (2.35m^2) that was more than twice the mean area of disturbance at the montane site (0.89m^2). Summary statistics for the categorical variables showed most TTFs at the coastal plain site (59%) and the montane site (94%) had moderate canopy openness. Location relative to trail was similar at both sites with two thirds of TTFs occurring on trail. Root exposure was predominant at both sites but a higher percentage of root exposure (89%) was found at the montane site. Only 7% of coastal plain TTFs and 15% of montane TTFS had poor understory conditions. In general, biophysical impacts were found at both sites and the amount of impact varied from site to site.

Table 6: Biophysical Impact Means from the Coastal Plain and Montane Sites

Assessment Variables	Coastal Plain Site	Montane Site
Area of Disturbance (m2)	2.35	0.89
Landscape Slope (^{o})	13.0	22.1
Trail Incision (cm)	16.9	20.6
Trail Slope (^{o})	12.3	22.8
Trail Width (m)	1.4	1.1

* All reported values are means

Table 7: Categorical Biophysical Impact Values at the Coastal Plain and Montane Sites

	Coastal Plain Site		**Montane Site**	
Assessment Variables	Count	%	Count	%
Canopy Openness				
Closed	21	24	6	3
Moderate	51	59	189	94
Open	14	16	6	3
Location Relative to Trail				
On Trail	57	66	134	67
Cleared Area	25	29	29	14
Natural Vegetation	4	5	38	19
Root Exposure				
Present	59	69	173	86
Not Present	27	31	28	14
Trail Type				
Narrow	3	3	63	31
One Person	61	71	88	44
Two Person	11	13	28	14
4 Wheel Drive	11	13	22	11
Understory Condition				
Poor	6	7	30	15
Light Vegetation	39	45	108	54
Thick Vegetation	41	48	63	31
Vegetation Removed to Construct TTF				
Present	41	48	24	12
Not Present	45	52	177	88

4.2 Technical Opportunity Conceptual Framework

A main focus of this study was the applicability of the technical opportunity framework (Kollar & Leung 2010) to the montane site. Within this framework, ground, traverse, and aerial technical opportunities were used as a means to explain variance in biophysical impact assessments variables that were evident in the general site assessments shown in the previous section. The composition of TTFs within the technical opportunity groups changed significantly from the coastal plain site to the montane site (**Figure 9**). Traverse TTFs (52%) were the most common at Coastal Plain while ground TTFs (17%) were the least common. In contrast, the dominant technical opportunity group at the montane site was the aerial group (56%) with the traverse group (16%) being the least common. Ground TTFs went from the least common group at the coastal plain site to the second most common group at the montane site.

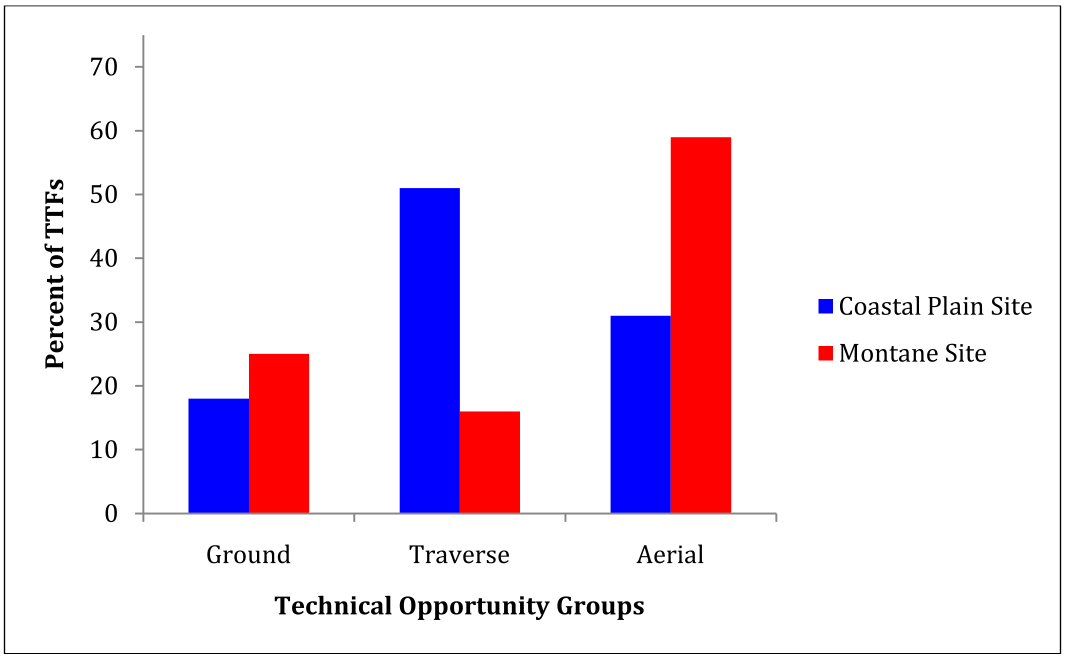

Figure 9: Percentage of TTFs in the Technical Opportunity Groups at Coastal Plain and Montane Sites

4.2.1 Categorical Biophysical Assessment Data

Non-parametric statistics, in the forms of Chi-Square Analysis and Cramer's V, were used to analyze the variance of biophysical impact assessments that involved categorical data across technical opportunity groups. A Cramer's V test was used to determine the effect size between the independent and dependent variables studied (Pallant, 2007). A large effect size would indicate that a strong relationship occurred between the technical opportunity groups and a specific biophysical impact variable. The five dependent variables used to assess resulting biophysical impacts within the technical opportunity framework were; location of TTF relative to trail, presence of root exposure, trail type, understory condition, and the presence of native vegetation removed to construct the TTF (**Table 8**).

Table 8: Chi-Square Analyses of Biophysical Assessment Variables Using Technical Opportunity Framework at Coastal Plain and Montane Sites

	Coastal Plain Site		**Montane Site**	
Assessment Variables	**ChiSquare**	**P>ChiSq**	**ChiSquare**	**P>ChiSq**
Canopy Openness	19.317	0.001	1.525	0.822
Location Relative to Trail	17.761	0.001	58.452	<0.001
Root Exposure	8.388	0.015	8.292	0.016
Trail Type	16.567	0.011	5.191	0.520
Understory Condition	18.274	0.001	0.589	0.965
Vegetation Removed to Construct TTF	11.036	0.040	6.597	0.037

* Significance level set at 0.05

In the chi-square analysis, all five dependent variables were significantly different at the 0.05 level between ground, aerial, and traverse groups at the coastal plain site. According to the Cramer's V value and degrees of freedom for each response variable, all biophysical impact variables had either medium or large effect sizes (**Table 9**). Three of the five response variables at the montane site were significantly different; location of TTF to trail ($p<0.001$), presence of root exposure ($p<0.016$), and presence of native vegetation removed to construct the TTF ($p<0.037$). Of the three significantly different response variables at the montane site, only location of TTF relative to trail had a large effect size, meaning a strong relationship with the technical opportunity groups occurred. Presence of root exposure and presence of native vegetation removed to construct the TTF had small effect sizes, meaning that even though a significant difference was identified, the relationship between those specific variables and the technical opportunity groups was weak.

The chi-square analyses showed several relationships between the technical opportunity groups and biophysical impact variables. One example from the coastal plain site showed over 80% of aerial and ground TTFs had root exposure while only half of traverse TTFs had root exposure. At the montane site 70% of aerial TTFs and 90% of ground TTFs were located on trail while only 18% of traverse TTFs were found on trail. The majority (61%) of traverse TTFs at the montane site were located in natural vegetation. Using the technical opportunity framework in the chi-square analysis helps explain where biophysical impacts vary.

Table 9: Cramer's V Test and Effect Size of Biophysical Assessment Variables Using Technical Opportunity Framework

	Coastal Plain Site		**Montane Site**	
Assessment Variable	**Cramer's V**	**Effect Size**	**Cramer's V**	**Effect Size**
Canopy Openness[2]	0.474	Large	0.062	-
Location Relative to Trail[2]	0.321	Medium	0.381	Large
Root Exposure[1]	0.312	Medium	0.203	Small
Trail Type[3]	0.310	Large	0.114	-
Understory Condition[2]	0.326	Large	0.038	Small
Vegetation Removed to Construct TTF[1]	0.358	Medium	0.181	-

* Degrees of freedom used to determine effect size: [1] df = 1, [2] df = 2, [3] df = 3
Effect sizes for 1 degree of freedom (small =0.10, medium=0.30, large=0.50)
Effect sizes for 2 degrees of freedom (small=0.07, medium=0.21, large=0.21)
Effect sizes for 3 degrees of freedom (small=0.06, medium=0.17, large=0.29)

4.2.2 Continuous Biophysical Assessment Data

One-way ANOVAs were used to analyze variance in five continuous biophysical impact variables across technical opportunity groups within each study site. Tukey's Honestly Significant Difference (HSD) post-hoc test was used to indicate where the significant differences occurred. All five biophysical impact variables were significantly different ($p<0.05$) at the coastal plain site (**Table 10**). Within the coastal plain site, aerial TTFs recorded the highest mean values for slope, area disturbed, trail width, and trail incision. Traverse TTFs had the lowest mean scores for all biophysical impact variables except for trail width. According to the Tukey's HSD post-hoc test, the significant difference in trail width resulted from the aerial TTFs.

Table 10: One-Way ANOVAs for Impact Variables at Coastal Plain and Montane Sites

Variables	F-value	Pr>F	Technical Opportunity Groups[1]		
Coastal Plain Site			Ground	Traverse	Aerial
Area Disturbed	14.4	<0.001	54.9[a]	3.9[b]	37.9[a]
Landscape Slope	4.2	0.017	19.2[a]	10.0[b]	14.6[ab]
Trail Incision	10.0	<0.001	22.0[ab]	7.0[b]	30.2[a]
Trail Slope	21.7	<0.001	8.9[b]	5.5[b]	25.3[a]
Trail Width	6.9	0.002	100.1[b]	118.6[b]	188.6[a]
Montane Site			Ground	Traverse	Aerial
Area Disturbed	40.1	<0.001	20.9[a]	6.2[b]	4.6[b]
Landscape Slope	2.4	0.088	25.7	19.9	21.2
Trail Incision	20.4	<0.001	31.0[a]	11.2[c]	18.8[b]
Trail Slope	2.5	0.081	20.3	19.5	24.7
Trail Width	0.25	0.776	108.4	102.7	111.3

[1] Mean values. Groups with the same letter are not significantly different ($p = 0.05$) (Tukey's HSD post-hoc Test).

The one-way ANOVA for the montane site resulted in two significant differences for biophysical impact variables. Both area of disturbance ($p<0.001$) and trail incision ($p<0.001$) elicited significantly different results from the three technical opportunity groups. According to Tukey's post hoc test, the ground TTF group was responsible for the significant differences in area of disturbance and trail incision. It should be acknowledged that two response variables, landscape slope ($p=0.088$) and trail slope ($p=0.081$), were nearly significantly different. Ground TTFs had the highest mean values for area of disturbance, landscape slope, and trail incision. As found in the coastal plain site, aerial TTFs recorded the highest mean values for slope and trail width.

A two-way ANOVA was used to simultaneously examine the effects of two categorical independent variables on the same five dependent biophysical impact variables used in the one-way ANOVA. The two independent factors used in this analysis were the technical opportunity groups and the mountain biking sites. For this analysis, technical opportunity groups were nested within the independent variable for mountain biking sites to compare specific groups across sites (e.g., aerial TTFs at the coastal plain site and aerial TTFs at the montane site). Results from the nested two-way ANOVA show statistically significant effects for both technical opportunity groups and the mountain biking sites (**Table 11**). Overall, technical opportunity groups have a significant main effect on the variance of trail incision, disturbed area, trail slope, landscape slope and trail width. Also, a significant main effect on the variance of all five dependent biophysical impact variables was found for the nested mountain biking sites.

Table 11: Nested Two-Way ANOVA for Biophysical Impact Variables

Source	**T-O Group Effect**[1]		**Site (T-O Group) Effect**[2]	
Variables	F-value	Pr<F	F-value	Pr<F
Trail incision	4.7	<0.0001	21.7	0.0032
Area Disturbed	33.9	<0.0001	27.1	<0.0001
Trail Slope	17.9	<0.0001	8.7	<0.0001
Landscape Slope	4.9	0.0083	6.7	0.0002
Trail Width	5.7	0.0038	8.4	<0.001

[1] T-O = Technical-Opportunity
[2] Technical-Opportunity groups nested within the two sites.

4.3 Spatial Arrangement of TTFs

The spatial arrangement of TTFs at mountain biking sites has not been characterized in the literature. TTFs can exist alone as individual features or in groups as first documented by Pickering et al., (2010a). By representing the TTFs spatially the arrangement of TTFs in relation with each other, the trail, and proximate natural features becomes visible. In the spatial representations of the coastal plain (**Figure 10**) and montane sites (**Figure 11**), each technical opportunity group is represented by a color and a symbol.

At the coastal plain site trails were designed in circular loops with a main trail providing access from the entrance to the different loops. The TTFs were spread out through the site with long segments of trail occurring between the TTFs. The spatial arrangement of TTFs was examined using a buffer analysis of TTF locations at the coastal plain and montane sites (**Table 12**). Buffer sizes were determined from the length of TTFs because it was used as the radius for the COZs.

Table 12: Clustering of TTFs at the Coastal Plain and Montane Sites

	Coastal Plain Site	Montane Site
TTF Frequency (TTF:trail length)	1:150	1:70
Percent of TTFs in Clusters	42	57
Percent of TTFs Not in a Cluster	58	43
Cluster Count	6	25
Largest Cluster Size	9	12
Average Cluster Size	5	5
Percent of Ground TTFs in Clusters	9	15
Percent of Traverse TTFs in Clusters	16	4
Percent of Aerial TTFs in Clusters	20	36

* A cluster is defined as 3 or more TTFs with overlapping buffer zones

More than half of TTFs at the montane site (57%) were arranged in clusters, which were defined as three or more TTFs with overlapping buffer zones. The coastal plain site had a slightly smaller percentage of TTFs in clusters (42%) and a smaller maximum cluster size of nine. The percentage of TTFs in clusters, total number of clusters and the cluster sizes were all higher at the montane site. Also, aerial and ground TTFs were not only grouped with themselves but also with each other. General patterns of technical opportunity groups showed that aerial features were the most likely to be arranged in clusters at both montane (20%) and coastal plain (36%) sites. This indicates that some overlap was occurring within the impact zones as defined by the COZ.

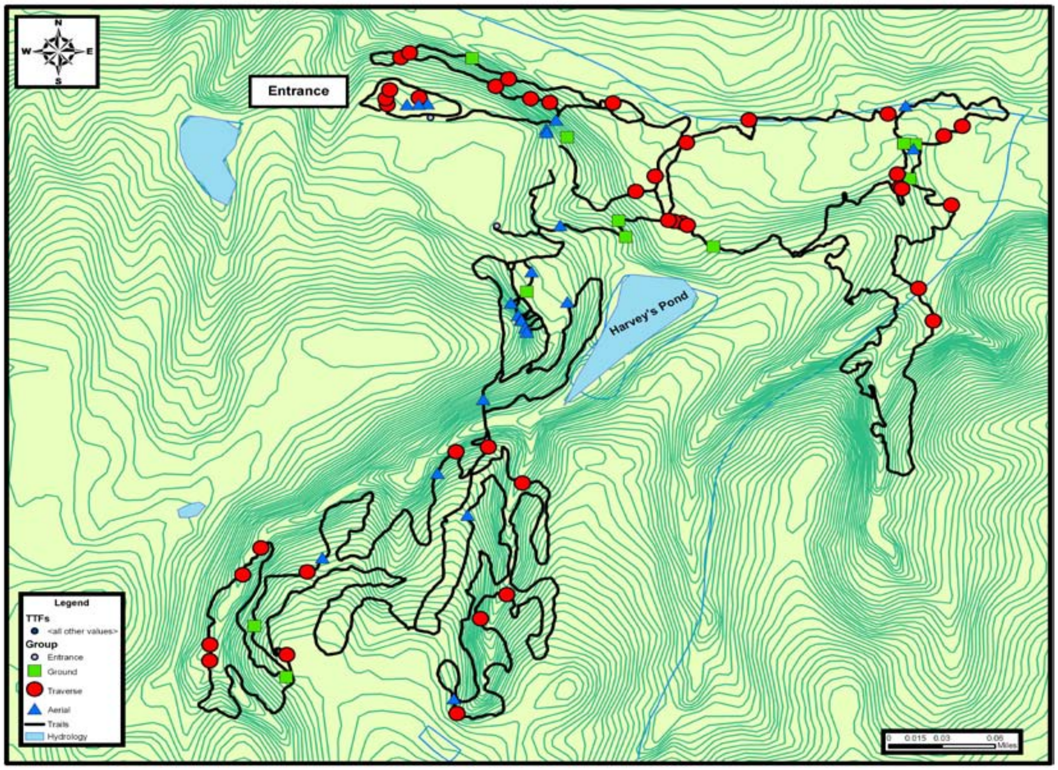

Figure 10: Spatial Arrangement of TTFs at the Coastal Plain Site

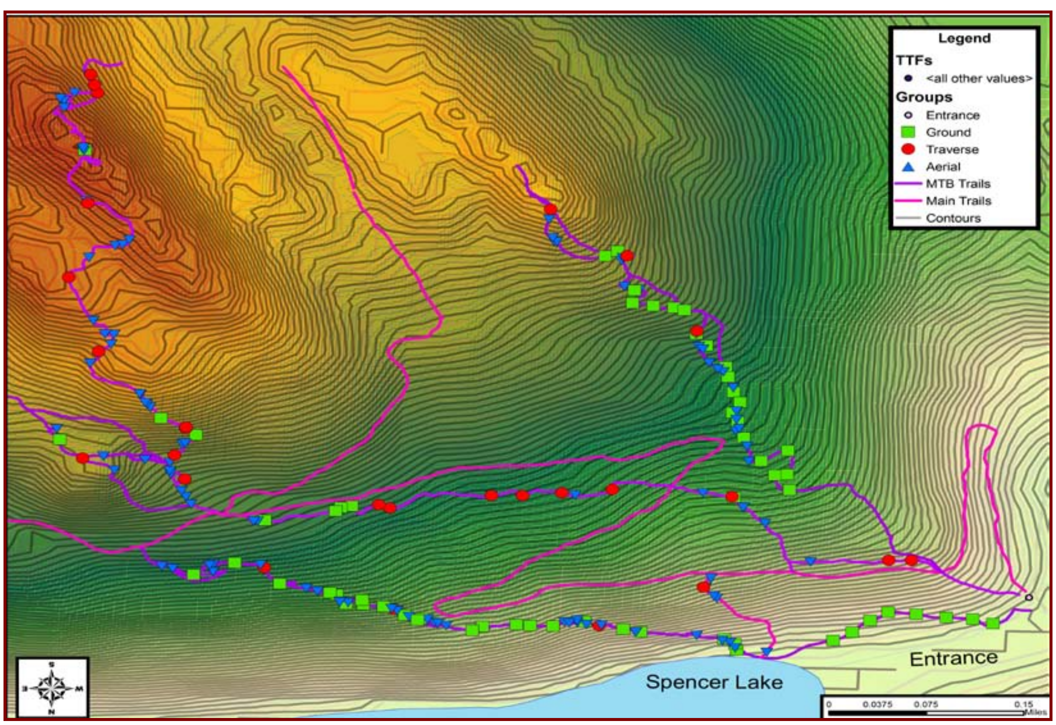

Figure 11: Spatial Arrangement of TTFs at the Montane Site

Technical trail features were frequently found at both the coastal plain and montane mountain biking sites. At each site, a wide range of TTF types and construction materials were found. Representation of technical-opporunity groups changed from heavily favored traverse features at the coastal plaine site to the aerial feature dominated montane site. Biophysical impacts also changed from site to site with the montane site yielding higher mean trail slope, incision, and root exposure. Further analysis using Chi-Square Tests and One-Way ANOVA's indicated that associations occurred among biophysical impacts and technical opportunity groups at both sites, especially the coastal plain site. The higher cluster frequency and sizes found at the montane site might have influenced the lack of assocation and will be discussed further in the next chapter.

CHAPTER 5: Discussion and Implications

No published empirical research in North America, where mountain biking originated, has examined or referenced the presence and use of TTFs. In addition, outdoor recreation research has neither questioned nor contributed to publically distributed guidelines for constructing and placing TTFs in various natural settings. Consequently, this research study set out to examine TTF characteristics, resulting biophysical impacts, and the spatial arrangement of TTFs at two distinct mountain biking sites. Application of the technical opportunity groups at the montane and coastal plain mountain biking sites was performed to test the applicability of the framework, not to characterize the physiographic region themselves. Assessments at several mountain biking sites within each physiographic area would be required to characterize biophysical impacts for each area. Instead, this research was designed to recognize and highlight differences in mountain biking site characteristics that have not been addressed by outdoor recreation research or mountain biking organizations.

This chapter focuses on three topics: general differences found between the mountain biking sites in two physiographic regions, applicability of the technical opportunity framework for characterizing biophysical impacts, and limitations of the study. A discussion of implications for future research and management of mountain biking TTFs concludes this chapter.

5.1 General Between-Site Differences

5.1.1 Frequency & Types of TTFs

It is not well known how many TTFs exist at mountain biking sites or what the carrying capacity is for a particular site. Often, natural resource managers know these TTFs exist but do not know how many or of what type. This is often the responsibility of mountain biking organizations that agree to self manage or regulate mountain biking and TTF use. The only known references of TTF frequency and variety come from two previous research studies that reviewed TTFs in Australia. In these studies, Newsome & Davies (2009) reported 18 TTFs for a frequency of 1 for every 140 meters at John Forrest National Park, and Pickering et al., (2010a) reported 116 TTFs consisting of 8 types at Blackbutt forest. No published empirical study on TTF frequencies or types at mountain biking sites within the United States exists.

In this study both the montane and the coastal plain sites had 14 types of TTFs which suggests that TTF variety was not significantly affected by the difference in site. The popularity and accessibility of mountain biking resources found on the internet and through mountain biking association publications are likely responsible for the diversity of TTF types found. Despite the similarity in variety of TTFs, a large difference in TTF frequency was found between the coastal plain and the montane sites. The coastal plain site had a TTF frequency of 1:150m which is much less than the 1:70m TTF frequency found at the montane site. This result countered one of the conclusions made from the methodological study by Kollar & Leung (2010) at the coastal plain site which suggested that flat mountain biking sites would incorporate more TTFs to compensate for the lack of challenging or technical natural terrain. Rather, the montane site incorporated more TTFs by complementing the already challenging natural terrain.

5.1.2 Construction Materials

TTF design has been influenced by the creativity of mountain bikers and through technical features found in other recreation activities. Mountain biking TTF types can vary in height, width, and length to contribute to the challenge of a trail (Pickering et al., 2010a). *IMBA's Guide to Building Sweet Singletrack* makes a distinction between natural TTFs and built TTFs based on the materials used to construct them. In the analysis by Kollar & Leung (2010) naturalness of TTFs (i.e., built, enhanced, and natural) did not explain the variance in biophysical impacts that resulted at the coastal plain site. However, the naturalness of the TTFs can indicate disturbance of the natural environment through collection, modification, and removal of natural resources.

Results from this study suggest three factors for determining disturbance of the natural environment when building TTFs: availability of durable natural resources onsite, effort required to transport materials, and the distance from trail access points to TTF locations. Examination of the construction materials at both sites showed TTFs at the montane site incorporated more native, natural building materials (e.g., soil, rocks) than the coastal plain site. Further support of this difference was shown in the biophysical assessment indicating that 88% of TTFs at the montane site required removal of native vegetation to construct the feature. Meanwhile less than half of TTFs at the coastal plain site were built with native vegetation. On several occasions during the assessment period at the montane site, mountain bikers were seen transporting materials and manipulating on site natural resources to construct TTFs (**Figure 12**).

The natural surface at the montane site contained an abundance of rocks (stony silt loam) and downed woody materials (Kallander, 2010). Availability of natural building materials combined with the effort required to transport materials and tools up 20-45% grades from one access point, suggests that native, natural building materials were preferred for building TTFs at the montane site. In contrast, the trail system at the coastal plain site had several access points, making it easier to incorporate foreign or non native building materials into TTF construction, hence requiring less manipulation of the natural environment. These three factors should be considered by natural resource managers before permitting the construction of TTFs at their sites and where informal TTFs exist.

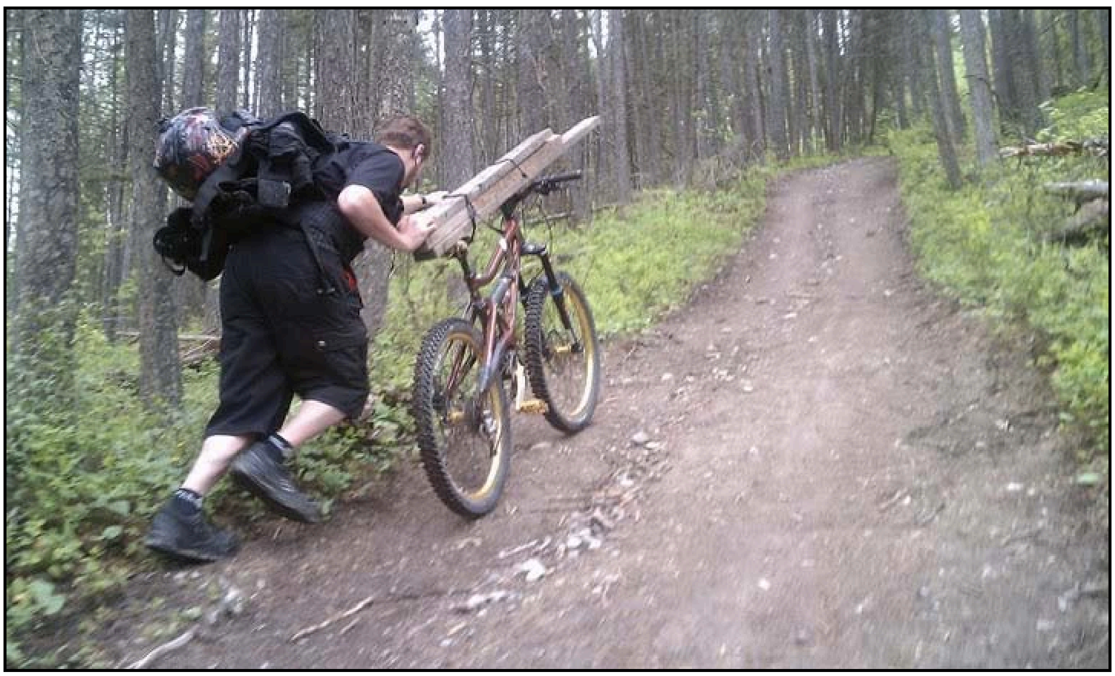

Figure 12: Transportation of TTF Building Materials Up Steep Slopes at Montane Site
* Picture was taken by the researcher during the assessment of TTFs at the montane site

5.1.3 Biophysical Impacts

The first biophysical impact analyses examined the characteristics of all TTFs found at both the coastal plain and montane sites. Categorical and continuous assessment data showed some similarities and differences between the two sites. TTFs at the montane site yielded higher mean values for trail incision, trail slope, and landscape slope. The association of steep trail slope and trail incision from mountain biking use has been well documented in previous biophysical impact studies by Wilson & Seney (1994) and White et al. (2006).

Another important development within biophysical impact research indicates that excessive trail widths can lead to increased areal extent of intensive trampling-related impact and erosion (Marion & Wimpey, 2010). TTFs at the coastal plain site had higher mean values for disturbed areas and trail widths. One possible explanation for the larger trail width and disturbed area is the loop trail system format. Mountain bikers at the montane site all travel in the same direction, which is the direction all TTFs are facing (i.e., downslope). At the coastal plain site riders approaching TTFs, especially aerial TTFs, from the opposite direction of TTFs must ride around the TTFs instead of participating. This scenario can also relate to mountain bikers traveling in opposite directions and moving off the trail or going around TTFs to avoid collision. A second explanation is that riders at the coastal plain site might have viewed the TTFs as unsafe or too difficult and hence chose to ride around them.

The majority of TTFs at both coastal plain and montane sites had presence of root exposure, were located on trail, with single user trail widths, and under moderate canopy cover. Common presence of root exposure around TTFs at both coastal plain and montane sites contrasts the findings of Pickering et al. (2010a) where no TTFs had root exposure. Differences between sites were found for understory condition and vegetation removed to construct features. Coastal plain site TTFs frequently had thick vegetation and showed little use of native vegetation for TTF construction. This result also contrasts the finding of

Pickering et al. (2010a) where nearly all TTFs involved the removal of vegetation to construct the feature. Contrastingly, TTFs at the montane site frequently required the removal of native vegetation to construct features and had light vegetation. General associations of all TTFs at a mountain biking site are important but they are very general and do not tell us where or why these biophysical impacts occur. A more productive way for explaining the biophysical impacts caused by TTFs is needed. A conceptual framework that organizes TTFs based on similar function or purpose might provide more beneficial information to research and managers.

5.2 Applicability of Technical Opportunity Conceptual Framework

The technical opportunity conceptual framework emerged from a methodological study by Kollar & Leung (2010) as one way to explain the variance of biophysical impacts occurring at mountain biking sites. In that study, ground, traverse, and aerial TTF groups varied in terms of the biophysical impacts resulting from the presence and use of TTFs at a coastal plain mountain biking site. To test the applicability of this conceptual framework it was applied to a montane mountain biking site. Overall, the technical opportunity groups were applied effectively at the two physiographically distinct mountain biking sites. All TTFs at the montane site were successfully fitted into one of the three technical opportunity groups, supporting their applicability. Further analysis of the technical opportunity framework will be addressed in the following sections. Since all TTFs fit into the technical opportunity groups, the next step was to examine the representation of ground, traverse, and aerial groups at both coastal plain and montane sites. Each TTF group was represented at both sites indicating that mountain bikers desire a variety of TTFs.

However, the representation of TTF groups at both sites was not equal (**Figure 8**). Differences found in TTF group representation between the two sites suggest that specific TTF groups might be preferred at specific mountain biking sites. This could result from differences in natural terrain or technical opportunities desired by the local mountain biking population. Using the results from the one-way ANOVAs we can make inferences about the differences found in TTF group representations at the montane and coastal plain mountain biking sites.

At the montane site aerial TTFs were clearly the most dominant technical opportunity group. The large representation of aerial TTFs might be related to the nature of aerial opportunities and the steep trail slopes found at the montane site. The coastal plain site, with a much smaller mean trail slope, favored traverse TTFs which were associated with smaller trail slope according to results from the one-way ANOVA (**Table 10**). Ground TTFs were not dominant at either site but were more prevalent at the montane site. At the montane site the second most common TTF type, berms, are part of the ground TTF group. According to Webber (2007) and the *TTF Identification Guide* (**Appendix A**) created in Kollar & Leung (2010), berms are in-sloped turns that help riders carry momentum through corners. Since all trails at the montane site flow downhill it is likely that berms or ground TTFs were designed to help riders carry their momentum down the steep trail slopes without traveling directly down the fall line.

5.3 Continued Development of the TTF Assessment Methodology

A major focus of this study was the continued development of an assessment methodology that can measure biophysical impacts from TTF use. One-way ANOVAs at each site focused on major biophysical assessment variables (i.e., trail slope, landscape slope, trail incision and trail width) that have been used in previous mountain biking assessment studies. The initial ANOVA at the coastal plain site found significant differences among the three technical opportunity groups for all five assessment variables. Aerial TTFs were associated with larger slopes, trail widths, disturbance areas and trail incision (**Figures 13 & 14**). Surprisingly, traverse TTFs, which tend to be built TTFs, had the lowest mean values for area disturbance and trail incision. One explanation is that traverse TTFs (e.g., bridges, boardwalks, skinnies) protected against the impact instead of the natural surface. This coincides with the concept that traverse TTFs provide a technical opportunity that occurs off the ground on an overlaying surface. In contrast, ground TTFs had the highest mean disturbance area. Ground TTFs occur on the natural surface, absorb all of the impact and hence are more susceptible to disturbance. At the coastal plain site we found relationships between the technical opportunity groups and specific biophysical impact assessment variables.

As seen with the non-parametric statistical tests, the montane site had less variance among the dependent biophysical assessment variables. Area disturbed and trail incision were the only significantly different assessment variables. Similar to the coastal plain site, ground TTFs had the highest mean disturbance area. Since mean trail slope and mean trail incision were highest for aerial TTFs at the coastal plain site it was expected that the steep trail slopes at the montane site would show a similar response. Surprisingly, no significant difference occurred among the three technical opportunity groups for mean trail slope (**Figure 15**). The overall steep character of the terrain combined with the clustering of

TTF group types might have changed the relationship found at the coastal plain site. Another unexpected result was that ground TTFs at the montane site had the highest mean trail incision (**Figure 16**). This contradicts results from the coastal plain site and the documented association of larger trail incision with larger trail slopes found in previous mountain biking studies.

Figures 13-16: Distribution of data for trail slope and trail incision assessment variables at the coastal plain and montane sites. Within each figure the shapes indicate the distribution of responses for that particular variable. The width of each shape represents the number of TTFs per technical opportunity group. Height of each shape represents the range in response with the mean value in the middle. Differences in mean responses or vertical location of the shape indicates significant differences for the assessment variable of interest.

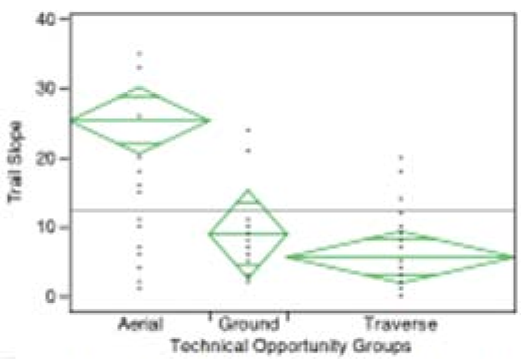

Figure 13: Trail Slope at Coastal Plain Site

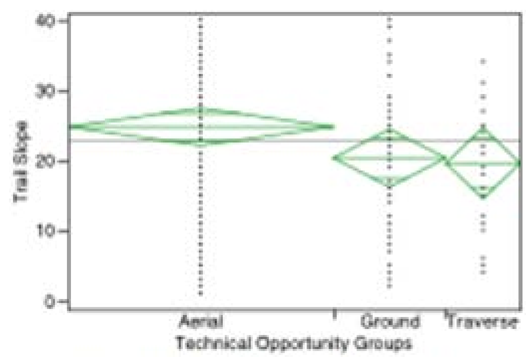

Figure 15: Trail Slope at Montane Site

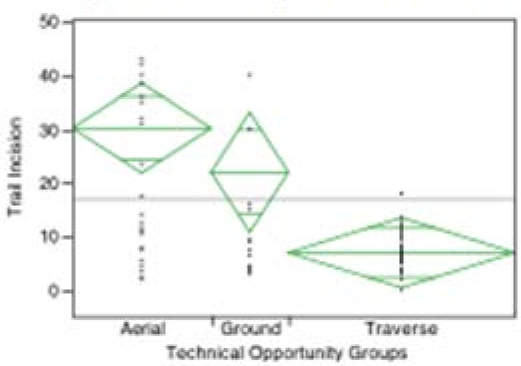

Figure 14: Trail Incision at Coastal Plain Site

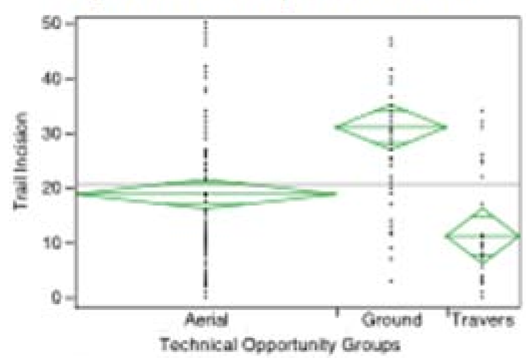

Figure 16: Trail Incision at Montane Site

Results from the nested two-way ANOVA indicated that both technical opportunity groups and site were significant factors in explaining differences in biophysical impacts. Combination of all assessment data from both sites resulted in significant differences between the technical opportunity groups for trail incision, trail slope, landscape slope, area of disturbance and trail width. This suggests that the ground, traverse, and aerial TTF groups might have broader utility in differentiating among the biophysical impacts of TTFs.

The site variable proved to be an important factor for differentiating among biophysical impacts. Specifically, technical opportunity groups nested within the site variable were able to explain differences among the continuous biophysical assessment variables. In this nested two-way ANOVA we focused our analysis on the variance of similar groups between sites (e.g., aerial TTFs at Spencer Lake and aerial TTFs at the coastal plain site). In each case, significant differences occurred. This result suggests that biophysical impacts are dependent on the site. Continued application of the technical opportunity framework at other mountain biking sites within each physiographic region would help substantiate this result. The nested two-way ANOVA provides a unique way to compare specific TTF technical opportunity groups across sites but is limited because no interaction effect can be measured between the two independent variables of site and TTF Groups.

5.4 Spatial Arrangement of TTFs

The spatial arrangement of TTFs was not uniform at either site. Examples of large clusters found at the montane site can be seen in **Figure 17**. The arrangement of TTFs within the clusters was not uniform either. TTFs within the clusters also varied between the montane and coastal plain sites. For example, 52% of clusters at the montane site contained both ground TTFs and aerial TTFs (**Figure 18**). Also, the coastal plain site showed that 42% of clusters contained both ground TTFs and aerial TTFs. It is possible that significant relationships occur between TTF groups and could provide further understanding of biophysical impacts and mountain biking site design.

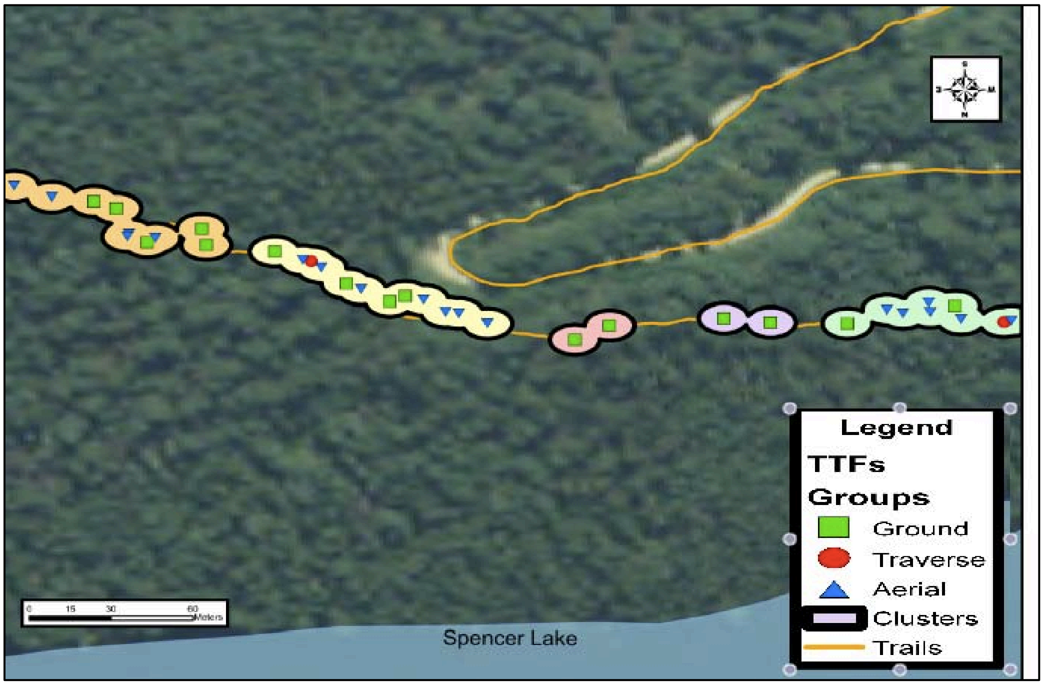

Figure 17: An Example of TTF Clustering at The Montane Site
* Different colors represent different clusters. Symbols represent TTF technical opportunity groups.

Figure 18: Example of Aerial TTF Preceding a Ground TTF at the Montane Site
* Pictured above is a drop-off leading to a berm.

5.5 Study Limitations

Several important limitations exist in this study. First, it is impossible to guarantee that mountain biking sites are not visited by other recreationists. Although, both study sites were chosen partly because they were specifically designed for mountain biking, it is plausible that hikers or horseback riders have contributed to the biophysical impacts found at both sites. This issue remains a constant problem for mountain biking assessments since the activity was introduced much later than hiking and horseback riding and hence has typically been restricted to multiple-use trails.

Only a handful of research studies have looked at the biophysical impacts of mountain biking. Only ten published studies, six in the U.S. and four in Australia, have looked at the biophysical impacts of mountain biking (Pickering et al., 2010b). Even less research has focused on the presence and use of TTFs and their resulting biophysical impacts. The small amount of research available limits the ability to compare results found in this study. This study combined with the two Australian studies by Pickering et al, (2010a) and Newsome and Davies (2009) incorporate only four mountain biking sites in the world. Clearly, more mountain biking sites with TTFs need to be investigated before conclusive statements can be made about the relationships, patterns and trends reported in these studies.

Another limitation of this study is that only two sites were used in the characterization of mountain biking impacts regarding TTFs. The introductory nature of developing a TTF assessment methodology meant that numerous assessment items, 30 in this study, were used. The time required to perform 30 assessments per TTF was a limitation for the field data collection. Lengthy assessment periods and the high quantity of TTFs found at each site, made it difficult to assess more than two study sites. If biophysical impacts from TTFs are to be characterized for specific physiographic regions, then a larger sample of mountain biking sites at both coastal plain and montane areas is required.

The technical trail features themselves were a limitation for assessments in this study. At the coastal plain and montane site TTFs are formally acknowledged and managed. However, the history of each TTF found in this study is not well known. It is difficult for researchers and managers to discern what TTFs were added formally and which were built informally. The distinction of informal and formal is important for the assessment because informal TTFs are not subjected to safety and biophysical standards. A similar study limitation comes from the age and use of TTFs. At the montane site, some TTFs might have been constructed 15 to 20 years ago while other TTFs were recently added. Unknown TTF history potentially limits the certainty of safety and biophysical assessments.

5.6 Implications for Future Research

Results from the study have several implications for future recreation ecology research. For mountain biking, TTFs were shown in this study to have zones where biophysical impacts occur. Certain assessment variables such as root exposure, trail incision, area of disturbance, and vegetation removed to construct features were important indicators of impact. Future research of mountain biking and TTFs should continue to focus on these variables. Other variables like canopy cover and understory condition were not important biophysical impact indicators. By focusing on specific biophysical impact variables researchers could decrease the assessment time in future assessments. Also, variables like canopy cover, soil, and vegetation condition can be assessed through aerial photography and LIDAR data that have become more accurate and available.

One benefit of using the technical opportunity framework to explain biophysical impacts is that it lends itself to other areas within natural resource research. Few studies have examined the behavioral and biophysical aspects of mountain biking together (Geoft & Alder, 2001). Biophysical impacts of mountain biking were the main focus of this study, but there are implications for other forms of research including behavioral and geographic information science (GIS). Integrated research efforts from all aspects of mountain biking research would be most beneficial to natural resource managers. One avenue for mountain biking research collaboration is through the study of TTFs.

Behavioral research focused on understanding how and why mountain bikers use TTFs would aid in recreation impact research and management of mountain biking. Previous mountain biking studies have already looked at rider preferences for turns or curves, bumps, jumps, and steep slopes (Chiu & Kriwoken, 2003; Geoft & Alder, 2001; Symmonds et al., 2000). Similar studies could examine motivations and preferences for using certain TTFs and/or technical opportunity groups. This could provide insight into why differences in TTF frequency and variety occur at different mountain biking sites or physiographic regions. Perhaps this could extend to preferences for TTFs based on the distinctions among mountain biking rider styles.

At the most basic level TTFs could be one component of recreation specialization. Previous studies about recreation specialization have focused on single activities (Manning, 1999). It is well known that within mountain biking many rider styles exist (IMBA, 2007;

Ryan, 2005). Diversification of mountain biking into numerous rider styles suggests that rider styles could be perceived as subactivities. Within each specific activity, subactivities are likely to have different degrees of specialization (Manning, 1999). TTFs might be one way to determine the degree of specialization within mountain biking. Specific rider styles or subactivities might have different preferences for TTFs or TTF groups. Initial study suggests that biophysical impacts might relate to specific riding styles especially technical or adventure oriented styles like downhill and freeriding (Newsome & Davies, 2009; Pickering et al., 2010b). Hence, relationships among specific rider styles and TTFs might be a useful tool for predicting the frequency and types of TTFs and possibly biophysical impacts.

In addition, place attachment and recreation specialization could incorporate TTFs and the technical opportunity framework. Place attachment and recreation specialization have been shown to be related in recreation research (Manning, 1999). Newsome & Davies (2009) listed attachment to site as a potential environmental, social, and management issue with TTFs. Subsequent creation of informal TTFs after removal by natural resource managers suggests that some level of attachment exists at specific mountain biking locations. Future studies could examine the relationship of place attachment on TTF presence at certain sites.

Ultimately, TTFs and the technical opportunity framework could be studied in conjunction with resource substitution. Other forms of behavioral research like recreation specialization and motivations have already been shown to be related to substitutability (Manning, 1999). Resource substitution research could examine how likely mountain bikers would be to substitute certain TTFs or TTF groups. Ultimately, combining behavioral and biophysical impact research efforts could inform management decisions for designing more sustainable mountain biking sites. Sustainable mountain biking design would continue to provide mountain bikers with opportunities (e.g., TTFs) to create desired experiences while considering and protecting the natural resources where these experiences occur.

This study also presents many implications for the expanding research field of GIS. More thorough study of the spatial arrangement of TTFs and biophysical impacts is still needed. Future study of mountain biking TTFs using GIS could look at patterns for consecutive TTFs. Certain TTFs might occur together more frequently than others. Spatial relationships could be tested for the arrangement of TTFs around natural features such as slope or water. In terms of biophysical impact, GIS techniques (e.g., hot spot analysis) could be used to examine spatial patterns of mountain biking disturbance like erosion and vegetation trampling.

5.7 Management Implications

Results from this study have many implications towards the management of mountain biking and TTFs. First, mountain biking sites are unique. Both descriptive and analytical results from this study show that TTF characteristics and biophysical impacts differed from site to site. Montane and coastal plain designations were applied to the study sites to acknowledge that mountain biking sites have unique vegetation, soils, animals, and histories. Consulting mountain biking association publications for site design and management strategies can be helpful. However, managers should keep in mind that these documents have been generalized to reach a broader audience. Consideration of site specific or region specific characteristics should be given before implementing specific management strategies for mountain biking use.

Implications also come from the different assessment items within the methodology. Assessment variables that were not strong indicators of biophysical impact in this study were canopy openness and understory condition. Only a small portion of TTFs in this study had either open canopy (<15%) or bare understory conditions (<15%). Results from the study suggest that root exposure, trail incision, and vegetation removed to construct TTFs were important biophysical impacts that occurred at both sites. For managers these are the key assessment variables that could be used in future assessments to inform decisions on mountain biking and TTFs. Another implication coming from the assessment methodology is the presence of shared impact zones. The buffer analysis results showed that TTFs do occur in clusters. Within these clusters it is difficult to assess what biophysical impacts are resulting from specific TTFs. Managers should be aware that large, shared zones of impact can result from the clustering of TTFs. As a result managers should consider limiting the clustering of TTFs especially in environmentally sensitive areas.

The technical opportunity framework has many implications for management. First, it is an efficient method for examining TTFs because it collapses all TTFs into three groups. Second, through this study numerous relationships have been found among ground, traverse and aerial TTFs and biophysical impacts. For example, ground TTFs had the highest trail incision at both the montane and coastal plain sites. Also, the technical opportunity groups show which types of TTFs were the most frequent at each site like aerial TTFs (59%)

at the montane site and traverse TTFs (51%) at the coastal plain site. Resource managers looking to incorporate TTFs at their site they could use this information to make decisions about what TTFs to incorporate, how many TTFs are appropriate, and how the TTFs should be arranged spatially.

As mountain biking continues to grow and diversify, resource managers will need an efficient way to monitor all aspects of mountain biking at their sites. In the case of TTFs it is often difficult to keep accurate and current information about these features. Addition of informal TTFs at mountain biking sites has led not only to unnecessary biophysical impacts but also safety risks creating potential land manger liability concerns (Webber, 2007). Managers need to start monitoring their mountain biking trails and TTFs for environmental and safety reasons.

A basic management issue concerning TTFs is that their names are not commonly known by natural resource managers and sometimes even by the mountain bikers themselves. To assist natural resource managers, a TTF identification guide (**Appendix A**) was compiled in Kollar & Leung (2010) that incorporated the names, descriptions and pictures of all known TTFs. This TTF identification guide provides a first step towards understanding TTFs. At the very least, natural resource managers and their partners can use the *TTF Identification Guide* with a GPS unit to monitor TTF types, quantity, and locations at their sites. A detailed procedure for using GPS with free online programs to monitor TTFs can be found in the method section of this study. This monitoring technique allows managers to view a picture of the TTF and all previously recorded assessment data (**Figure 19**). In essence, managers can document the unique history of each TTF and organize TTF assessment data into a more manageable format.

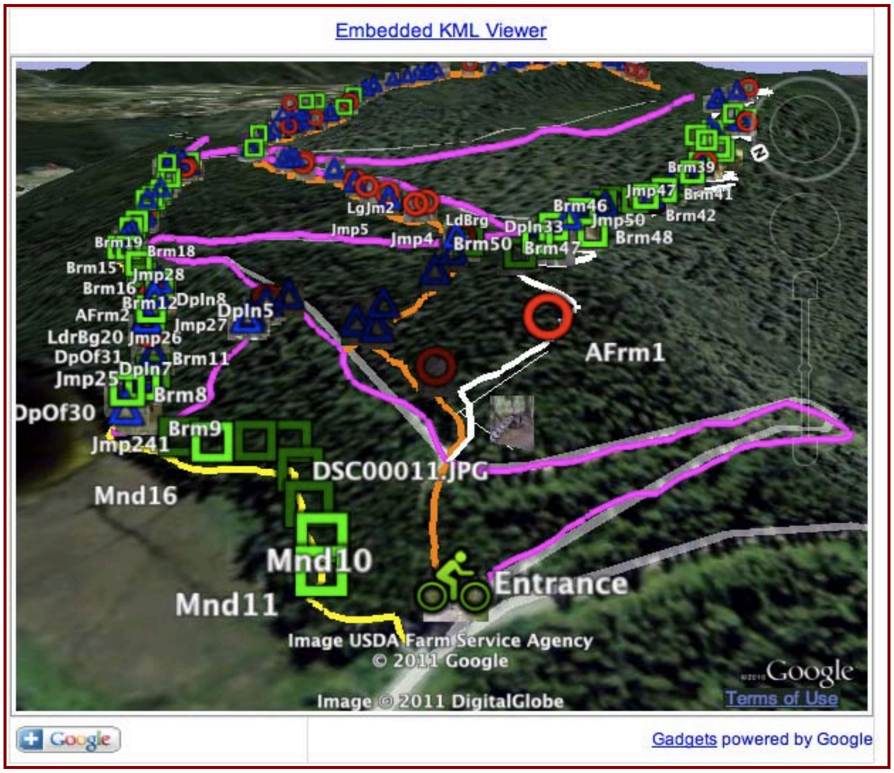

Figure 19: Web Enabled Assessment Monitoring Technique Using Google Earth
* Pictured above are the assessments and geotagged pictures of TTFs at the montane site

In the United States, visitor impact research has focused on the development of impact indicators and feasible monitoring programs (Pickering et al., 2010a). In accordance, assessments performed in this study purposely used standard, low cost tools whenever possible. However, it was assumed that natural resource managers would have access to standard trail tools, a simple GPS unit, and a computer with internet access. Design of this methodology makes it feasible for natural resource managers to use this protocol to efficiently monitor TTFs and biophysical impacts. It might also be useful for managers to display mountain biking trails, TTFs, and pictures on their websites. This could help inform visitors about the quantity, variety and condition of TTFs found at a specific site. In this manner, monitoring by resource managers could promote visitor safety and natural resource protection. A web-enabled monitoring program might also be useful for attracting specific rider styles to a particular recreation site.

Initial management concerns about TTFs arose from the potential for injury to mountain bikers. Due to their technical nature, TTFs are potentially dangerous to all mountain bikers even those considered experts. To address this concern, IMBA and other mountain biking organizations have produced manuals for incorporating safety elements into trail design. Examples of safety elements include; filters or choke points, fall zones, optional lines, signage, and space between TTFs (Webber, 2007). In this study TTF safety assessments were performed to see whether IMBA safety guidelines referenced in Webber (2007) were being followed or ignored. In one case, the combined results from the coastal plain and montane sites showed the presence of only 4 signs. Although this indicates safety precaution guidelines are not being closely followed by natural resource managers and mountain biking associations, it does agree with results from a study of mountain bikers at Tsali recreation area by Bowker and English (2002) that found preference for signage was ranked near the bottom in terms of importance. Resource managers should monitor mountain biking associations to make sure they are following the guidelines and ethics that they have proposed not just the preferences of riders.

CHAPTER 6: Conclusion

The purpose of this study was to address a gap in mountain biking impact research by examining technical trail features at two physiographically distinct mountain bike sites. Continued application of an adaptive assessment methodology revealed that certain impact indicators (i.e., root exposure and trail incision) were more significant than others for assessing mountain biking TTFs. On the other hand, certain assessment variables like trail and landscape slope were more significant indicators of biophysical impact at the coastal plain site than the montane site. Results from the study indicated that TTFs did cause biophysical impacts and those impacts varied depending on the type of TTF. More specifically, employment of a technical opportunity framework was important for characterizing impacts to specific TTFs at both the coastal plain and the montane sites. Application of this framework within a proximity analysis yielded patterns for TTF location in regard to the trail and to each other. Despite its exploratory nature, this study provides a basis upon which future research can build to further our understanding and management of mountain biking.

However, the study of mountain biking TTFs is not limited to the field of recreation ecology. Correlated social science research is equally needed to address the challenge with mountain biking impacts and management. Understanding rider preferences and behavior regarding TTFs is critical for addressing the biophysical and safety concerns that the features present. It is possible that specific rider styles (i.e., freeride) prefer specific TTFs of certain groups of TTFs (i.e., technical opportunity groups). Social science research could be integrated with the biophysical impact research such as results from this study to assist with the design of mountain biking sites or networks.

Mountain biking sites are often designed cooperatively by trail engineers, resource managers and mountain biking associations (e.g., IMBA). However, there has been little cooperation among resource managers. With the support of recreation research, resource managers could work together to design mountain biking sites that tailor towards specific rider styles based on biophysical conditions. For example, a site with excessive slopes and wet soil may not be appropriate for certain TTFs or rider styles. In this case, a large network of mountain biking sites could be formed to provide mountain biking opportunities based on biophysical conditions. Cooperation among resource managers and large scale planning efforts might be more preferable and feasible than having numerous sites all trying to provide opportunities for all rider styles. Hence, a carefully integrated approach is needed to provide accurate information to resource managers who want to provide opportunities for mountain biking experiences while preserving the resource where they occurs.

Providing adequate mountain biking opportunities in the appropriate settings is part of a larger, growing challenge for natural resource managers. Mountain biking is only a recent addition to the increasingly complex, multiple-use natural resource management strategies employed in the United States. With emerging recreation activities and changing biophysical conditions, the term "sustainability" has become an important concept in natural resource management. Considering the recent growth in emerging recreation activities like geocaching and off-highway vehicles resource managers will have to determine what they can sustainably manage (Monz, Cole, Leung, & Marion, 2010). Adaptive assessment methods, like the one employed in this study, can be used quickly and effectively to determine the biophysical impacts associated with specific recreation activities. Integration of adaptive assessment methods with the web-based visitor impact monitoring program developed in this study can help alleviate mixed perceptions of impact. This study represents one way that recreation ecology can assist with the challenge of providing opportunities for numerous recreation activities within multiple use natural resource management.

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APPENDICES

APPENDIX A: TTF Identification Guide

The following is an independent document providing mountain biking terms, definitions, and pictures. All information was collected through mountain biking internet sources and are referenced at the end of the document. This compilation of mountain biking information is NOT a direct work of the author(s) but a reference tool for researchers and resource managers. In certain cases, pictures, definitions, and terms have been modified for clarity.

I. References:

The following websites were used to compile pictures and definitions for mountain biking technical trail features:

1. http://crankfernie.com/
2. http://www.dieselbikes.com/tech/
3. http://www.forestry.gov.uk/forestry/INFD-6YSDCM
4. http://www.imba.com/
5. http://www.mountainbikedictionary.com
6. http://www.whistler.ca/images/stories/.../trail_standards_first_edition.pdf
7. http://www.abc-of-mountainbiking.com

II. General Mountain Biking Terms:

Armoring:
Large rocks used to "pave" a trail and prevent erosion. Trail builders in soggy areas are forced to armor entire pathways with stone to escape year-round mud. Large rocks are buried in the tread, making the trail interesting and dry. When using rock for armoring try to isolate boulders that take two or three people to move. This ensures that the rock will remain in place for a long time. Bury at least a third of the rock in the ground: take time to place it permanently and make it appear natural. Experiment with different rock placements and mimic natural outcroppings.

Enhanced Natural Features:
Manipulation of natural materials to create technical trail features. Use rocks and logs to create drop-offs, rock gardens, boulder rides, log pyramids and log rides. Building enhanced natural features is a good way to add technical challenge to trails where existing challenging terrain is limited.

Existing Natural Features:
The easiest way to build a technically challenging trail is to incorporate existing natural features. Route the trail over rock slabs, ledges, rock gardens and fallen trees. Employing these naturally occurring features as control points during trail design and layout will highlight the landscape and minimize social trails.

Fall Zone:
A fall zone is the area adjacent to a technical trail feature that provides a clear landing for a rider who has failed to negotiate the obstacle. Fall zones are located at the bottom of descents, on the outside of corners, and on the side of the trail. Another option is to add mulch or dirt to further soften a fall zone. Consider removing branches, stumps, logs, rocks and other protruding objects that could cause injury.

Freeride:
A style of mountain biking riding that usually involves large drops, jumps, and manmade features. A type of mountain biking that has a strong emphasis on airborne tricks. The trails are sometimes accessed by shuttle or ski lift but can be pedaled to as well. Freeride bikes often have shorter wheel bases for low speed stability, lighter frame than downhill bikes but still strong due to big impacts from tricks. Freeride bikes mostly have single crown suspension forks allowing tricks such as tail whips and bar spins to be carried out.

Man-made Structures:
Another way to increase challenge on a trail is to add man-made structures. Ladder bridges, wooden ramps and teeter-totters are prime examples. These structures often require artificial materials such as processed lumber and fasteners.

Optional Line:
There should always be an easier, alternate route around a technical feature. An optional line is an alternate route around the technical trail feature. On advanced trails, the technical trail feature can be located on the main line with an easier option to the side. On intermediate or beginner routes, technical trail features should be outside the main trail flow, and potentially even disguised from the main trail. Optional lines could potentially be in the same corridor as the main trail. For example, a drop-off could vary in height from one side of the trail to the other.

Technical Terrain:
Terrain that is more challenging than normal. It might require skillful bike handling to pass. Normally involves multiple changes in terrain (i.e., mud, rock, loam, north shore features, and obstacles).

Technical Trail Features:
Objects that have been introduced to the trail to add technical challenge. An obstacle on the trail requiring negotiation, the feature can be either man made or natural, such as an elevated bridge or a rock face respectively. Examples include: rocks, logs, elevated bridges, teeter-totters, jumps, drop-offs, etc. Both the height and the width of technical trail features are important.

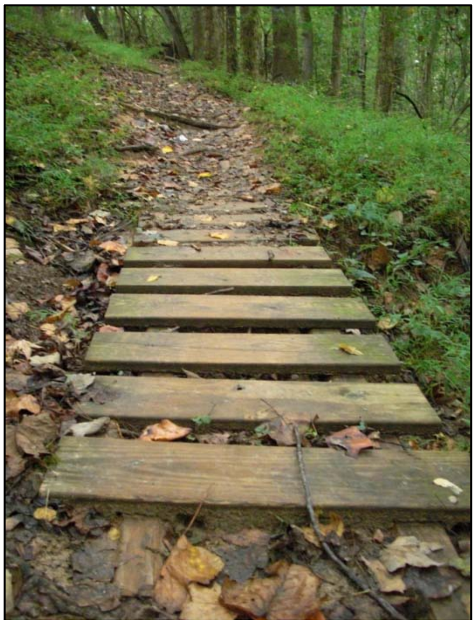
III. Technical Trail Features:

A-Frame:
Two ramps (i.e., approach and exit) placed together with no level section at the apex. Typically used to bridge deadfall across the trail.

Balance Beam:
Logs placed lengthwise next to the trail can also provide a unique challenge. For some users the log will function as a balance beam, while others will use it as a bench to rest on. It's important to set these logs or pieces of wood into the ground so they don't roll. Place them upslope of the trail where they won't impede drainage.

Berm:
A steeply banked corner which it's possible to take at speed. Insloped turns, usually called berms by mountain bikers, help riders carry momentum through corners. Berms keep riders on the trail and, perhaps most importantly, they are fun to ride. Berms must be placed in the right spot in the trail corridor and be the correct height, length, and radius. Berms should naturally draw the rider in and should shoot the rider back out of the corner at a greater speed. Berms have the potential to trap water, so it is essential to utilize slope/grade reversals to improve drainage before and after the corner. Berms can be as short as 1 foot and as tall as you want to go. The faster a rider enters the corner, the taller, longer, and wider the berm should be. Berms are often built too far from the turn's apex, which can cause riders to make a tighter turn in order to cut the corner. Move the entire berm toward the apex of the turn if this happens, as the fastest line through a corner should use the berm.

Bridge:
A structure that is built above and across a river or other obstacle allowing passage across or over obstacle. Typically, shorter in length than boardwalks.



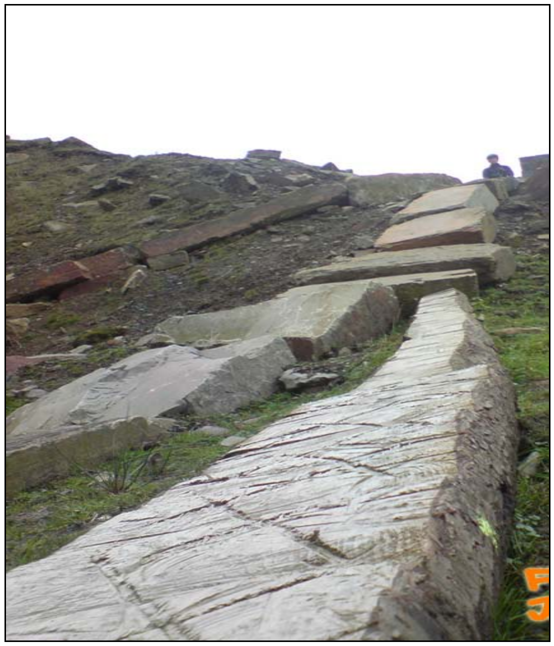
Boardwalk:
A raised walkway made of boards, used to traverse sensitive areas. Typically, extends over long distances.

Bomb Hole/Ditch:
A large crater-style hole that riders drop into or jump over.

Boulder/Rock Garden:
Trail routed over and through existing rocky areas. These rocky sections batter bikes and is also appealing to hikers and equestrians. People expect rocks in nature and won't avoid them if they seem natural. The key is that no matter how difficult the rock section might be, it still must be the easiest route through that area. This gives riders no other choice but to stay on the trail, avoiding trail-widening or shortcuts.

Drop Off:
A steep and sudden drop in the trail. A drop in the trail, possibly at the end of a log or off a rock; might require a technique depending on the vertical drop and/or the angle of descent. Often a vertical drop down the side of a rock. Drop-offs are some of the most fun and challenging natural features on a downhill trail. Like jumps, they must be visible and clearly marked to allow riders to smoothly pass around or off the drop - even when approaching at high speed. The approach should be a little slower than the actual take-off so that riders don't have to hit their brakes right at the top. The landing area should be wide and sloped downhill, and it should be carefully located to allow riders to hit the drop at full speed without overshooting the landing zone. Utilize natural ledges or construct short drop-offs with rock. This addition on a contour can challenge riders both ascending and descending. A six-inch-to-a-foot drop is appropriate for most users. Make sure the drop-offs fit with the overall flow of the trail. Use them in bike-length series in an area where riders won't be taken by surprise. This spacing also makes it possible to climb, as well as descend. Transitions are important: a tight turn following a drop would cause riders to skid or shoot off the trail. Higher drops can employ two possible lines on the same trail - one difficult and one easier using a ramp or chock stone.

Gateway:
A qualifier before a trail or TTF. For example, a 2x4 piece of wood placed before an elevated bridge or a difficult corner. If the rider can successfully negotiate the technically challenging gateway, then they will likely be able to negotiate the TTF.

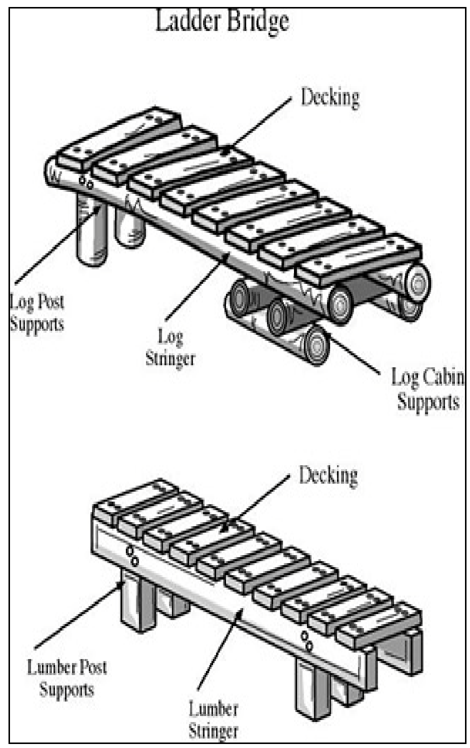


Gap Jump:
Two ramps placed back to back with space between them, the rider must travel with enough velocity to cross the space and land on the second ramp.

Jump:
A wedge shaped feature built with the intention of sending the rider airborne.

Ladder:
A TTF with rungs attached to sides made of metal, wood or rope. A feature used for climbing up or down.

Ladder Bridge:
Ladder Bridges are a key staple in providing the ability to cross areas like swamps and small streams. However they also can provide the ultimate challenge when properly built. The width of a ladder bridge can range from greater than 12" to 48" depending upon its requirement and/or desired mountain biking challenge. Typically, ladder bridges that are used for multi-use trails (i.e. bikers, joggers, hikers etc) are required to maintain a width of 34" ~ 36". In general, a good rule of thumb for the width of a ladder bridge when used as a technical trail feature is 12" - 20". That is as long as you are not using a section of the bridge as a landing area. Ladder bridges can be constructed to achieve an endless array of technical challenges. Structure distance, incorporating turns and changing elevation all provide adjustable attributes ultimately leading to the rider developing his or hers technical skills. When building a ladder bridge for TTF use, you should start small and increase the challenge in phases**.**



Log Choke:
A series of logs staggered on either side of the trail can provide a narrow choke that enhances the ride. This strategy can slow users and add challenge. Make sure the narrowing flows naturally with the trail. Otherwise people will find it annoying instead of interesting, and they might create a new route around it. Conflicts between mountain bikers and other trail users are often a result of the faster speeds that bikes travel. One way to slow mountain bikers is by narrowing the tread, creating tight points, and adding curves.

Logjam:
A pile of logs placed near or perpendicular to the trail. Usually placed in front of and behind deadfall to ease passage.

Log Ramp:
A popular trail management technique that uses a pile of logs to create a ramp up and over an existing fallen log. A well built log ramp will use at least 8-10-inch diameter logs. They might need to be fastened in place: use rope or wire, not dangerous spikes. Be careful on shared use trails because these flimsy ramps are a big obstacle to horses and hikers. Make sure to leave an easier option.

Log Ride:
Either a straight log or a group of logs stacked in a row that is not build for air or jumps.

Log Steps:
Large logs used to construct short steps or drop-offs. This addition can challenge riders in an area without technical, natural terrain. Make sure the step fits with the overall flow of the trail. Use them in bike-length series in an area where riders won't be taken by surprise. Transitions are important: a tight turn following a step is awkward. Be sure to account for water flow.

Off Camber:
The opposite of a berm, when the slope hinders cornering at speed.

Rock Choke:
A series of boulders staggered on either side of the trail can provide a narrow choke or slot that enhances the ride. This strategy can slow users and add challenge. Make sure the narrowing flows naturally with the trail - otherwise people will find it annoying instead of interesting, and might create a new route around it.

Rollers:
A section of repeated uphill and downhill sections that need little pedaling because momentum does most of the work. Usually part of a pump track.

Roll Over:
Usually a rock that gets steeper the farther the rider advances, to the point where stopping might not be an option. The rider must continue despite not being prepared for what is ahead.

Switchback:
When the trail turns tightly on a climb and goes back on itself. Also known as a hairpin. Can be used to move riders along the trail and challenge them with speed and turns.

See-Saw/Teetor-Totter:
A TTF consisting of a long plank balanced on a central support for riders to cross over, providing a down motion as the rider passes over the pivot. Just like a seesaw in a city park, but for mountain bikes. Ride slow in the middle to allow the see-saw to drop gently!

Skinny:
A wooden beam, roughly 6 inches or less in width, raised off the ground.

Step Down:
A much less severe version of a drop-off. Drop can be softened by wood or rocks.

Step Up:
A step in the trail that requires you to lift the front wheel first, quickly followed by the back wheel.

Tabletop:
A ramp leading to a plateau, with a ramp down the other side. Two camel bumps with the gap between them filled in. Two jumps back to back with void between the jumps filled in with dirt, creating a table top.

Whoop-De-Doo:
Successive jumps along a trail. Term used to refer to small jumps in a trail, usually in groups. Also known as moguls. This term is from skiing, referring to similarly shaped hills on ski slopes.

APPENDIX B: Field Procedure Forms

Environmental Assessment Protocol for Mountain Biking Technical Trail Features
Spencer Mountain, Whitefish MT. May19th-June1st 2010. Version # 2.

I. Purpose and Scope

This assessment protocol was developed to support objective assessments and monitoring of technical trail features (TTFs) created or used by mountain bikers. TTFs are intended for enhancing the technical challenges, excitement or enjoyment of mountain biking riding experiences. Information collected includes locations, type, size and dimension, and condition of these features as well as natural resource damage in nearby areas attributable to the presence and use of these features. This information can inform park managers and mountain biking groups in planning and managing sustainable mountain biking infrastructure and in developing user education/communication strategies. This protocol addresses only the technical features themselves and does not include assessment procedures for trail corridors in general.

In order to conduct this assessment efficiently two field staff would be needed, though it could be conducted by one field staff.

II. Equipment/Materials

- Assessment protocol manual and adequate supplies of field data form "A" and surveys "B"
- “Mountain biking Technical Trail Features Defined” handout (Kollar 2009)
- Writing/clip board or file folder
- Pencils
- Measuring wheel (metric)
- Measuring tape (metric)
- 20-cm or longer ruler (metric)
- Spherical Densiometer
- SUUNTO Tandem clinometer/compass combo
- GARMIN GPS Unit (Oregon 550 w/ digital camera, or Garmin GPSMAP 60csx)
- Digital camera (if no Oregon unit available)
- New or full-charged batteries (for GPS and camera)
- Hard-copy topographic map of the park
- Soil Survey Map

III. Definitions

Technical trail features (TTFs) can be defined armored, natural features or built structures that enhance mountain biking riding experiences through physical and mental challenges. There are two ways of categorizing trail features: compositional or technical opportunity. Categorization by composition groups TTFs based on materials belonging to the feature and how it came to exist (e.g., naturally, enhanced or built). Natural TTFs (NTFs) include challenging terrains such as slope, drop-offs, rolling topography, rough surfaces, etc. They exist naturally but the mountain biking trail is routed to take advantage of such features on the land. Built TTFs (BTFs) are those that are created by humans through armouring or rearrangement of natural features on the ground, or through introduction of foreign materials. Examples of BTFs include balance beams, ladders, bridges, logjams, etc. More examples of TTFs are provided in a supplementary handout. The second categorization involves three groups (aerial, ground and traverse) that encompass the technical opportunities provided by all technical trail features. Aerial features allow riders to challenge themselves through the air and against gravity. Ground features challenge riders to maneuver through technical terrain on the ground. Traverse features take riders from point A to point B on a structure that removes the rider from the trail. The challenge presented by the feature and skill required can change based on the dimensions of the feature but the provided technical opportunity remains constant.

IV. GPS Setups

- Fully charged batteries should be used
- Compass should be calibrated and set to azimuth degree readings if possible
- Select WAAS option in setup
- Use NAD83 datum and metric units

V. Procedures for specific measurement items

1. Technical Trail Feature Characteristics:

Data Type	Method/Unit	Details
GPS Location	Assess/ Y-N	Map a GPS waypoint at the center of the TTF. Check 'Yes' when done, or 'No' if GPS unit is unavailable (for latter, make the best effort in marking the location on a paper map)
TTF Type	Assess/ Categorize	Record the general type of TTF based on how it is constructed. Strengthened/armored natural features are considered built features. N - Natural Bo – Built, with on-site natural materials only Bf – Built, with off-site/foreign materials (natural or non-natural)
Feature Type	Assess/ Descriptive Name	Record the type of TTF based on the function it serves or the riding opportunities it provides. These terms come from the mountain biking community. Refer to the handout illustrating different examples with photos. Write down the feature name. Examples include: A-frame, bridge, camber, ditch, drop-off, jump, ladder bridge, log, mound, see-saw, others
Materials Used	Assess/ Categorize	This measure is for Built TTFs only (Bo or Bf). List essential materials used for building the TTF. Examples include: Brick (B), concrete (C), metal (M), nails (N), plastic (P), sandpaper (SP), wood (W). For other materials, write down short description
TTF Group	Assess/	Which technical opportunity is the TTF providing. Aerial (A), ground (G) or traverse (T)
TTF Max. Heights	Measure/ Meters	Measure maximum height on both sides of the TTF structure.
TTF Width (Max / Min)	Measure/ Meters	Measure the maximum and minimum width on the TTF structure. If the TTF structure has multiple components (e.g., two ends), take the maximum or expanded width that encompasses all components.
Total Length	Measure/ Meters	Measure the length of the TTF structure. If the feature has multiple components record the longest length measurement.

2. Safety & Management Issues:

Data Type	Method/Unit	Details
Feature Condition	Assess/ Categories	Record the extent to which the TTF is being maintained and updated, or whether it is deteriorating. Poor/deteriorating (P), Good (G) or Like New (N)
Feature Safety	Assess/ Categories	Assess structural integrity and built correctly. Low (L), Moderate (M), High (H) or Very High (VH)
Signage Present	Assess/ Categories	To warn users of upcoming feature. Yes (Y) or No (N)
Filters / Choke Points Presence	Assess/ Categories	Usually logs or objects used to funnel riders onto a narrow path to approach trail feature. Yes (Y) or No (N)
Optional Lines Around Features	Assess/ Categories	Safety route or trail for users to bypass trail features. Yes (Y) or No (N)
Fall Zones	Assess/ Categories	Usually accompany drop offs or features that send riders into the air. Area of soft ground or trail that provides users an area to exit the feature safely. Yes (Y) or No (N)

3. Environmental Impacts:

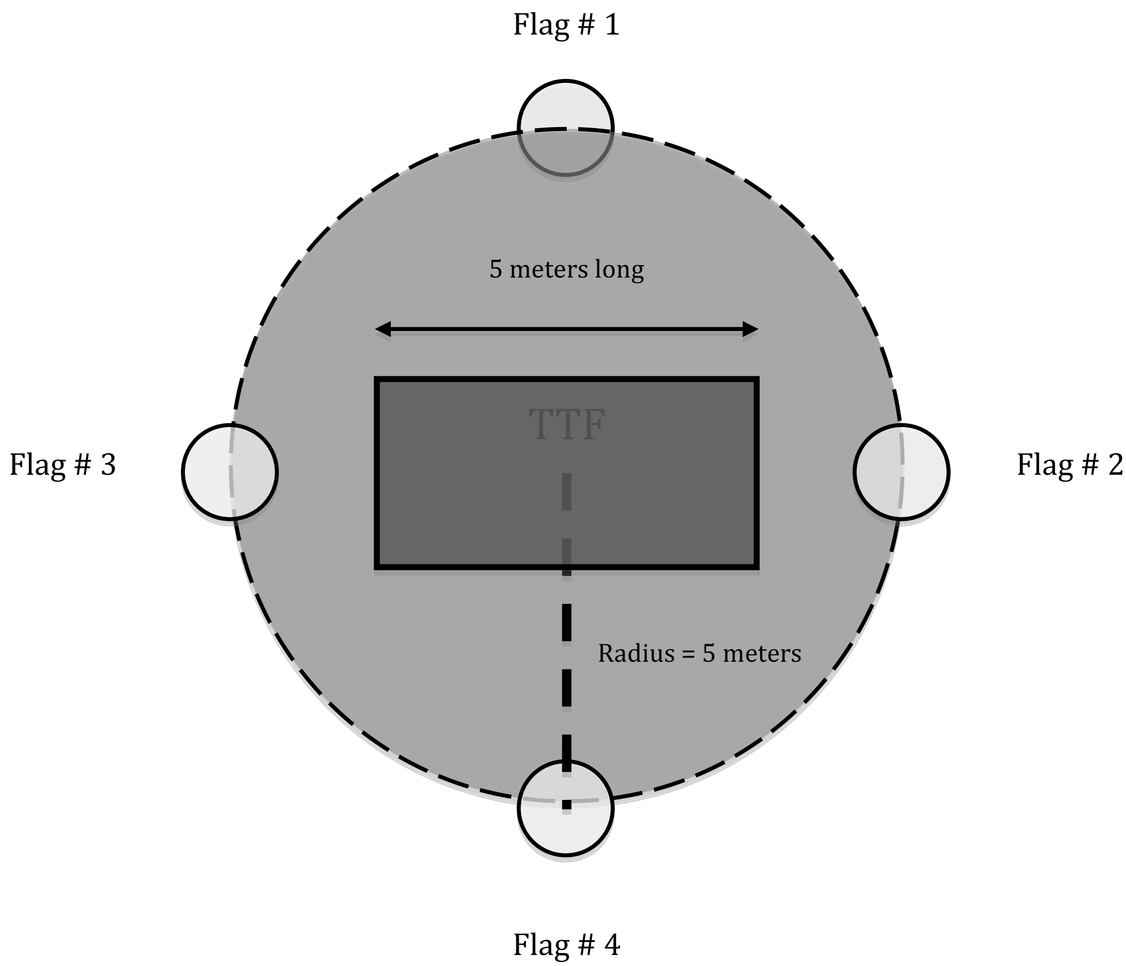
Circular Observation zone -- Measurements in this and the next sections take place within a circular observation zone (COZ) which is defined based on the size of TTF. Using the midpoint of TTF as the COZ center, the COZ radius is defined as the length of TTF. For example, a TTF that is 5m long will have a COZ with a 5m radius extending from the midpoint of the TTF (Figure 1). Four flags will be positioned to mark the perimeter of the COZ. A diagram illustrating the COZ is provided at the end of this document.

Data Type	Method	Details
Trail Incision or Depth	Measure/ Centimeters	Measure the incision depth of trail at entrance/exit point of the trail features. Use ruler and tape measure (or telescopic ruler that extends across the trail tread.
Size of Disturbed Area	Measure/ Centimeters	Measure the width and length of disturbed or barren area(s) around trail and TTF that is directly linked to the use of TTF. If there are multiple areas, measure each area in the field and calculate the total in office. Use tape measure.
Native Vegetation Removed to Construct Feature	Assess	Record whether natural vegetation has been cut, repositioned, or otherwise changed to construct the TTF. Yes (Y) or No (N)
Roots Exposed	Assess	Record whether there is exposed tree roots due to erosion that is occurring within the COZ. Yes (Y) or No (N)

4. Trail Components: Performed within the COZ as described above.

Data Type	Method	Details
TTF Location Relative to Trail	Assess/ Categories	Describe the relationship between the TTF and the main trail corridor. ON – TTF on trail If Off-Trail: CA - Cleared Area NV - Natural Vegetation
Trail Type	Assess/ Categories	Record the overall trail type based on its width. N – Narrow (just large enough for a bike tire,15-60cm) 1- One Person (one person shoulder to shoulder) 2- Two Person (two persons side by side) 4 - 4 wd (large enough for an off road vehicle)
Trail Width	Measure/ Centimeters	Measure the typical width of trail tread around the TTF using tape measure. Trail tread is defined as the actual walking surface of a trail as indicated by trampled vegetation, pulverized soil or changed microtopography. Do not record the width of expanded treads immediately adjacent to the TTF as it would be recorded as disturbed area.
Trail Slope	Measure/ Percent	Measure the trail slope between the two flags on the opposite side of the circular plot using the SUNNTO clinometer. Measurement should be taken from downslope (facing upslope).
Landscape Slope	Measure/ Percent	Measure the landscape slope along the fall line (max. drop) along the perimeter of the circular plot using the SUNNTO clinometer. Measurement should be taken from downslope (facing upslope)
Trail Aspect	Measure/ Degree	Use eye-scope while facing downslope. Azimuth degrees (0-359)
Landscape Aspect	Measure/ Degree	Use eye-scope while facing downslope. Azimuth degrees (0-359)
User	Assess/ Categorize	Observation of users while performing the on-site assessment. Biker (B), Hiker/Walker (H) or Runner (R)
Canopy Cover	Measure/ Percent	Record the canopy cover using the spherical densitometer. There are a total of 24, 1/8” x 1/8” squares in the grid. Each square represents an area of canopy opening (sky image or unfilled squares) or canopy cover (vegetation image or filled squares).Count the number of canopy opening squares. The uncovered area is determined by multiplying the number of squares by 4.17. Subtract this number from 100% to determine overstory density in %.e.g., 100% - (10 unfilled squares x 4.17) = 58.3% overstory density.
Canopy Openness	Categorize	Based on Canopy Cover Categorize the Canopy Openness Closed (C), Moderate (M) or Open (O)
Understory Condition	Assess/ Categorize	Record the overall coverage of understory vegetation. Poor (P), Light Vegetation (L) or Thick Vegetation (T)
Ground Cover	Assess/ Categorize	What vegetation types are found within the COZ Grass (G), Saplings (S), Adult Trees (T), or Shrubs (R)

Figure 1: Circular Observation Zone (COZ) for Trail Component and Environmental Impact Measurements



APPENDIX C: Field Data and Survey Forms

Field Data Form A

I. General Information

A. Park/Site Name:________________________________

B. Date _____/______/_______ (mm/dd/yyyy)

C. Start Time___________ am/pm

D. End Time___________am/pm

E. Weather:____

F. Data Collected By:____

G. GPS Unit Model:____

II. TTF Tallies

H. Total Number of Built Technical Trail Features (BTF) ________________

I. Total Number of Natural Technical Trail Features (NTF)_________________

J. Total Number of Aerial Technical Trail Features_________________

K. Total Number of Ground Technical Trail Features_______________

L. Total Number of Traverse Technical Trail Features_______________

M. Number of Users Observed __________________________________ (slash marks)

N. General Comments:

Field Survey Form(s) B - Following Two Pages

1. Technical Trail Feature Characteristics:										2. Safety & Management Concerns:			
TTF Name	TTF Type	Feature Type	TTF Group	Material Used	Height		Width		Total Length	Feature Condition	Feature Safety	Signage Present	Filters / Choke Points Present
					Max	Min	Max	Min					

3. Environmental Impacts:					4. Trail Components:										
Trail Incision	Area Distrb	Veg Remov to Construct TTF	Root Exp	TTF Location To Trail	Trail Type	Trail Width	Trail Slope	Landscape Slope	Trail Aspect	Landscape Aspect	User	Canopy Cover	Canopy Openness	Understory Condition	Groun Cover

APPENDIX D: Supplemental Table and Figures

Technical Trail Feature Frequencies

		Study Site		
		Spencer Mountain	Legend Park	Total
TTF Name	A-Frame	5	5	10
	Berm	46	5	51
	Bridge	1	17	18
	Board Walk	0	7	7
	Drop-In	23	0	23
	Drop-Off	36	17	53
	Jump	50	5	55
	Ladder Bridge	11	3	14
	Log Cross	9	4	13
	Log Jam	3	5	8
	Log Pile	1	0	1
	Rock Garden	0	4	4
	Skinny	2	3	5
	Tabletop	0	1	1
	Mound	11	4	15
	Whoop-de-doo	2	6	8
	Ditch	1	0	1
Total		201	86	287

Composition Based Technical Trail Feature Frequencies

		Composition Based TTF Groups			
		Built	Natural	Built	Total
Study Site	Spencer Mountain	64	44	93	201
	Legend Park	42	23	21	86
Total		106	67	114	287

Technical Opportunity Trail Feature Frequencies

		Technical Opportunity TTF Groups			Total
		Ground	Traverse	Aerial	
Study Site	Spencer Mountain	62	35	104	201
	Legend Park	19	44	23	86
Total		81	79	127	287

Condition Rating of Technical Trail Features

		TTF Condition			Total
		Poor	Good	Like New	
Study Site	Spencer Mountain	72	57	72	201
	Legend Park	32	47	7	86
Total		104	104	79	287

Safety Rating of Technical Trail Features

		Feature Safety				Total
		Low	Moderate	Good	Very High	
Study Site	Spencer Mountain	24	50	84	43	201
	Legend Park	22	29	33	2	86
Total		46	79	117	45	287

Signage Informing Rider of Technical Trail Feature

		Signage Present		Total
		No	Yes	
Study Site	Spencer Mountain	201	0	201
	Legend Park	82	4	86
Total		283	4	287

Filter or Choke Point Guiding Rider to Technical Trail Feature

		Filter / Choke Point		
		No	Yes	Total
Study Site	Spencer Mountain	173	28	201
	Legend Park	74	12	86
Total		247	40	287

Optional Line to Avoid Technical Trail Feature

		Optional Line			
		No	Yes	N/A	Total
Study Site	Spencer Mountain	97	104	0	201
	Legend Park	0	0	86	86
Total		97	104	86	287

Native Vegetation Removed to Construct Technical Trail Features

		Vegetation Removed		
		No	Yes	Total
Study Site	Spencer Mountain	24	177	201
	Legend Park	45	41	86
Total		69	218	287

Root Exposure Within Influence Zone of Technical Trail Feature

		Root Exposure		
		No	Yes	Total
Study Site	Spencer Mountain	28	173	201
	Legend Park	27	59	86
Total		55	232	287

Technical Trail Feature Location Relative to Trail

		TTF Location to Trail			Total
		On Trail	Cleared Area	Natural Vegetation	
Study Site	Spencer Mountain	134	29	38	201
	Legend Park	57	25	4	86
Total		191	54	42	287

Trail Type Relative to Technical Trail Feature Location

		Trail Type				Total
		Single Track	One Person	Two Person	Four wheel drive	
Study Site	Spencer Mountain	63	88	28	22	201
	Legend Park	3	62	10	11	86
Total		66	150	38	33	287

Openness of Canopy Relative to Technical Trail Feature Location

		Canopy Openness			Total
		Closed	Moderate	Open	
Study Site	Spencer Mountain	6	189	6	201
	Legend Park	21	51	14	86
Total		27	240	20	287

Understory Condition Relative to Technical Trail Feature Location

		Understory Condition			Total
		Poor	Light Vegetation	Heavy Vegetation	
Study Site	Spencer Mountain	30	108	63	201
	Legend Park	6	39	41	86

Understory Condition Relative to Technical Trail Feature Location

		Understory Condition			Total
		Poor	Light Vegetation	Heavy Vegetation	
Study Site	Spencer Mountain	30	108	63	201
	Legend Park	6	39	41	86
Total		36	147	104	287

One_Way ANOVA LP Composition Based Characterization of Technical Trail Features

		df	F	Sig.
Height Maximum	Between Groups	2	22.600	.000
	Within Groups	83		
	Total	85		
Width Maximum	Between Groups	2	19.899	.000
	Within Groups	83		
	Total	85		
Width Minimum	Between Groups	2	5.721	.005
	Within Groups	83		
	Total	85		
TTF Length	Between Groups	2	35.115	.000
	Within Groups	83		
	Total	85		
Trail Incision	Between Groups	2	21.130	.000
	Within Groups	83		
	Total	85		
Area Disturbed	Between Groups	2	.129	.879
	Within Groups	83		
	Total	85		
Trail Slope	Between Groups	2	22.190	.000
	Within Groups	83		
	Total	85		

Landscape Slope	Between Groups	2	3.342	.040
	Within Groups	83		
	Total	85		
Trail Aspect	Between Groups	2	.976	.381
	Within Groups	83		
	Total	85		
Landscape Aspect	Between Groups	2	6.336	.003
	Within Groups	83		
	Total	85		

One-Way ANOVA for Legend Park Technical Trail Feature

	TTF Length (m)	TTF Maximum Height (m)	Trail Incision (cm)	Trail Slope (º)	Landscape Slope (º)
F-value (d.f. = 2)	6.262	7.981	6.620	3.474	4.046
P-Value Transformations	0.003 1/x	0.001 Lg10(x)	0.002 none	0.036 1/x	0.021 none
Ground Mean ± SE Range	 19.17 ± 2.648 8.00 - 42	 0.558 ± 0.061 0.16 – 1.04	 21.97 ± 5.783 3 – 65	 8.87 ± 1.570 2 - 24	 18.37 ± 2.708 1 - 37
Traverse Mean ± SE Range	 8.45 ± 1.051 1.00 - 25	 0.646 ± 0.075 0.20 – 2.81	 7.29 ± 0.614 0 - 18	 5.82 ± 0.848 0 - 20	 9.95 ± 1.686 0 - 50
Aerial Mean ± SE Range	 8.46 ± 1.453 1.00 - 35	 5.945 ± 1.051 0.17 – 19.22	 26.15 ± 5.903 2 - 150	 21.91 ± 3.669 1.00 - 64	 14.43 ± 2.180 1.00 - 38
Total Mean ± SE Range	 10.32 ± 0.952 1.00 - 42	 2.032 ± 0.437 0.16 – 19.22	 16.87 ± 2.586 0 - 150	 8.45 ± 1.051 0 - 64	 13.01 ± 1.243 0 - 50

One-Way ANOVA for Spencer Mountain TTF Categorization

		TTF Maximum Height (m)	Landscape Aspect		
F-value (d.f. = 2)		3.312			
P-Value Transformations		0.030 Lg10(x)			
Ground Mean ± SE Range		 0.7313 ± 0.1293 0.15 – 8			

Traverse Mean ± SE Range		0.9774 ± 0.1165 0.13 – 3.14			
Aerial Mean ± SE Range		0.1001 ± 0.1372 0.15 – 9.82			
Total Mean ± SE Range		0.9139 ± 0.0841 0.13 – 9.82			

One-Way ANOVA for Spencer Mountain Composition-Based TTF Categorization

		df	F	Sig.
Height Maximum	Between Groups	2	7.435	.001
	Within Groups	198		
	Total	200		
Width Maximum	Between Groups	2	1.862	.158
	Within Groups	198		
	Total	200		
Width Minimum	Between Groups	2	5.097	.007
	Within Groups	198		
	Total	200		
Feature Length	Between Groups	2	.731	.483
	Within Groups	198		
	Total	200		
Trail Incision	Between Groups	2	.694	.501
	Within Groups	198		
	Total	200		
Area Disturbed	Between Groups	2	1.705	.184
	Within Groups	198		
	Total	200		

Trail Width	Between Groups	2	2.748	.067
	Within Groups	198		
	Total	200		
Trail Slope	Between Groups	2	12.285	.000
	Within Groups	198		
	Total	200		
Landscape Slope	Between Groups	2	.008	.992
	Within Groups	198		
	Total	200		
Trail Aspect	Between Groups	2	.880	.417
	Within Groups	198		
	Total	200		
Landscape Aspect	Between Groups	2	.984	.376
	Within Groups	198		
	Total	200		

One-Way ANOVA for Spencer Mountain Technical Opportunity TTF Categorization

		df	F	Sig.
Hgt_Max	Within Groups	198		
	Total	200		
Wdt_Max	Within Groups	198		
	Total	200		
Tt_ Lgt	Within Groups	198		
	Total	200		
Trl_In	Within Groups	198		
	Total	200		
Sz_A_Dr	Within Groups	198		
	Total	200		
Trl_Wid	Within Groups	198		
	Total	200		
Trl_Slp	Within Groups	198		
	Total	200		
Lsp_Slp	Within Groups	198		
	Total	200		
Trl_Asp	Within Groups	198		
	Total	200		
Lsp_Asp	Within Groups	198		
	Total	200		

One-Way ANOVA for Spencer Mountain Technical Opportunity TTF Categorization

		df	F	Sig.
Hgt_Max	Between Groups	2	.662	.517
	Within Groups	198		
	Total	200		
Wdt_Max	Between Groups	2	11.113	.000
	Within Groups	198		
	Total	200		
Tt_ Lgt	Between Groups	2	41.668	.000
	Within Groups	198		
	Total	200		
Trl_In	Between Groups	2	17.532	.000
	Within Groups	198		
	Total	200		
Sz_A_Dr	Between Groups	2	36.884	.000
	Within Groups	198		
	Total	200		
Trl_Wid	Between Groups	2	.234	.792
	Within Groups	198		
	Total	200		
Trl_Slp	Between Groups	2	2.980	.053
	Within Groups	198		
	Total	200		
Lsp_Slp	Between Groups	2	2.961	.054
	Within Groups	198		
	Total	200		
Trl_Asp	Between Groups	2	2.775	.065
	Within Groups	198		
	Total	200		
Lsp_Asp	Between Groups	2	2.909	.057
	Within Groups	198		
	Total	200		

One-Way ANOVA for Spencer Mountain Technical Opportunity TTF Categorization

		df	F	Sig.
Hgt_Max	Between Groups	2	.662	.517
	Within Groups	198		
	Total	200		
Wdt_Max	Between Groups	2	11.113	.000
	Within Groups	198		
	Total	200		
Tt_ Lgt	Between Groups	2	41.668	.000
	Within Groups	198		
	Total	200		
Trl_In	Between Groups	2	17.532	.000
	Within Groups	198		
	Total	200		
Sz_A_Dr	Between Groups	2	36.884	.000
	Within Groups	198		
	Total	200		
Trl_Wid	Between Groups	2	.234	.792
	Within Groups	198		
	Total	200		
Trl_Slp	Between Groups	2	2.980	.053
	Within Groups	198		
	Total	200		
Lsp_Slp	Between Groups	2	2.961	.054
	Within Groups	198		
	Total	200		
Trl_Asp	Between Groups	2	2.775	.065
	Within Groups	198		
	Total	200		
Lsp_Asp	Between Groups	2	2.909	.057
	Within Groups	198		
	Total	200		

Chi-Square Analysis for SM Technical Opportunity TTF Categorical Data

	Spencer Mountain		Legend Park	
Study Variable	Kramer's V	Significance	Kramer's V	Significance
Feature Condition	0.174	0.017*	0.223	0.074*
Feature Safety	0.230	0.002*	0.224	0.196
Filter / Choke Point	0.176	0.045*	0.259	0.055
Vegetation Removed to Construct Feature	0.192	0.024*	0.471	0.000*
Root Exposure	0.206	0.014*	0.342	0.006*
Feature Location Relative to Trail	0.552	0.000*	0.344	0.000*
Trail Type	0.110	0.557	0.273	0.047*
Canopy Openness	0.061	0.825	0.299	0.004*
Understory Condition	0.055	0878	0.316	0.002*

Chi-Square Analysis for LP Technical Opportunity TTF Categorical Data

Variable	Kramer's V	Significance
Feature Condition	0.223	0.074*
Feature Safety	0.224	0.196
Filter / Choke Point	0.259	0.055
Vegetation Removed to Construct Feature	0.471	0.000*
Root Exposure	0.342	0.006*
Feature Location Relative to Trail	0.344	0.000*
Trail Type	0.273	0.047*
Canopy Openness	0.299	0.004*
Understory Condition	0.316	0.002*